Increasing space efficiency within a Vertical Lift Module at Benchmark Electronics, Inc.

Bachelor thesis Industrial Engineering and Management

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Preface

This thesis about space efficiency within a dynamic storing system is performed to complete my bachelor's program of Industrial Engineering and Management, at the Universiteit Twente.

I would like to thank some people for helping me during the performance of this investigation. First, I would like to thank Paul Hagen for the opportunity to do a bachelor assignment at Benchmark Electronics, Inc. I would also like to thank Ronald, John and Henri for supporting me by answering questions and providing feedback. I can certainly say that I learned a lot during the twenty weeks of performing my research at the company.

Furthermore, I would like to thank my supervisor from the University, Hans Heerkens. He gave me the support and confidence that I needed to successfully fulfill my thesis. I would also like to thank Peter Schuur for providing me with valuable feedback.

Lastly, I would like to thank Anouk and Robert, my buddies from the University. They were conducting research at Benchmark Electronics, Inc. at the same time as I was and provided the necessary distraction, feedback and coffee.

Cyrelle Tenhagen September 1, 2018

There appear to be two kinds of thinking in management research. These two ways of thinking are about how knowledge is actually accumulated. You have first the rationalists, thinking that knowledge is gained by exercise of reason and logic, and second the empiricists, who think that perception is the way to knowledge (Grayling, as cited in Shea). The two kinds of thinking causes managers and workers to think differently about things and thereby may come to different conclusions (Trought, as cited in Shea). This may lead recommendations in this report to be not as someone else from Benchmark would experience it (Shea, 2007, p. 26).

Management summary

Introduction

Benchmark Electronics, Inc. produces parts and subassemblies to companies all over the world. Their site located in Almelo has expanded significantly the last few years caused by increasing demand. Due to inefficient use of the space in current warehouses, there is not enough space anymore to store all incoming goods. One of the warehouses stores goods in a Vertical Lift Module, named Kardex ZKDX1001. This system uses bins to store parts. Every time a new delivery order is received, parts have to be stored inside a new bin. The Kardex is programmed this way to be able to apply FIFO. This storing procedure causes many bins to contain little content and at the same time having multiple bins occupied for identical parts. The maximum number of bins for one identical part has been set to two in this project. Data investigation showed that in this case 9% of the currently occupied bins should not contain content. In this thesis, an approach has been provided that could reduce the 9% of superfluous bins to 0%.

Approach

To develop a way to reduce the number of superfluous bins, the following tasks have been performed:

- Data investigation to superfluous bins;
- Visualizing the warehousing processes in the main warehouse;
- Performing a literature review;
- Conducting interviews with warehouse employees, supply chain analyzers, program managers, planners and purchasers;
- Provide questionnaires to employees with potential solutions.

Conclusion & Recommendations

Three options to reduce the number of bins per part are provided in this thesis: Placing identical parts in fewer bins, placing different parts in fewer bins, or implementing a new type of adjustable bins. All options are designed to enable FIFO picking based on MBA-number.

The first option to reduce the number of bins is preferred by Benchmark according to the provided questionnaire. This option can be performed with help of two approaches. The first is to locate parts in fewer bins in the storing stage and the second to relocate parts over fewer bins once every couple of weeks. Both approaches have its own pros and cons, but can reduce the number of superfluous bins from 9% to 0%.

To maintain low storing and picking times while applying one of the two approaches, it is recommended to apply a different storage assignment method. The literature review that was performed showed that class-based storage assignment can result in the lowest travel times of an AS/RS. For VLM systems in particular, locating parts based on classes also reduces the travel time of the system. Scholars state that in an VLM, multiple items for one order are often picked in one tour. Taking this into consideration when deciding about where to assign classes in the VLM can decrease travel times even more. In this case, items from one order are stored close together. Random allocation within the classes can make sure that space efficiency is maintained.

The class-based storage assignment method requires classification of parts to function appropriately. According to the AHP that was performed, the MC ABC classification method should enable the best results in maintaining space efficiency and low travel times of the VLM. A drawback of the MC ABC is that the company has to think about important criteria for the classification, which causes this method to require more work on forehand then other discussed methods. The OOS could be a good alternative classification method. This method scored just a little lower in the AHP and does not require the company to think about criteria.

If Benchmark chooses not to implement one of the provided possibilities to reduce the number of superfluous bins, their warehousing processes could still be improved by adapting the class-based storage assignment policy with MC ABC classification.

Reader’s guide

Chapter 1: Introduction

The first chapter provides an introduction of the company, the problem the company deals with and the motivation for this study. The analysis of the core problem of space issues that was found during preliminary investigation is further explained. Finally, the research goal and questions of this study together with an approach to achieve the goal are established.

Chapter 2: Theoretical Framework

In the theoretical framework, an approach is presented as a guideline for the study. Theories that are used during the research will be presented and elaborated in this chapter.

Chapter 3: Current situation

The current situation of the company is outlined in chapter 3. The core problem will be described in more detail and current warehousing processes are analyzed.

Chapter 4: Plan: The first PDCA-cycle

In the beginning of this chapter, causes of the core problem are provided to be able to make a choice for the PDCA-cycle. Thereafter, the first step of the PDCA-cycle, the “Plan”, is outlined. The chosen cause is investigated in more detail and possibilities to develop improvements are presented.

Chapter 5: Literature review

The literature review serves as an approach for finding solutions. First, possibilities to increase the number of locations in a VLM without increasing in physical floor space are outlined. Thereafter, methods to decrease throughput and increase travel time while maintaining space efficiency are investigated for a VLM in specific and AS/RS in general. Finally, possible classification methods for the most suitable storage method are presented.

Chapter 6: Do: Implementing improvement

The Do step of the PDCA-cycle will be performed in this chapter. The formula to determine the possible reduction is presented for the preferred solution of the employees. Two optional categories are presented by which the number of unnecessary bins can be reduced. Of which one of them having to sacrifice the degree of reduction.

Chapter 7: Plan for implementation

Two implementation possibilities are outlined:

1. Locating parts in bins already occupied bins in the VLM, after receiving
2. Relocating parts over fewer bins, once in a couple of weeks

Both possibilities can be realized with help of the following approaches:

a. Let Baan calculate the amount of free space within a bin
b. Export of inventory from the VLM
c. Physical checking of inventory

These possibilities and approaches will be further explained in chapter 7.

Chapter 8: Discussion of possibilities
In this chapter, the potential solutions will be analyzed further by discussing the pros and cons of each possibility.

Chapter 9: Conclusion, recommendations, and limitations
The conclusion will provide a final decision about the best methods to reduce unnecessary bins, the storage assignment and classification. The methods are underpinned, recommendations for all three are presented, and limitations of the study are presented.

Glossary

AS/RS	Automated storage and retrieval system: In literature, dynamic storing systems in general are known as AS/RS. These systems usually consist of racks served by cranes running through aisles between the racks. The AS/RS in use by Benchmark is a Vertical Lift Module
Baan	Vendor of ERP software. The software they supply is also called Baan. In this thesis, Baan always refers to the software. Baan is a specially designed for manufacturers in the aerospace and defense, automotive, high tech and electronics, and industrial machinery, which enables the system to meet the unique standards of Benchmark
Batching	The process of storing particular parts together at a location
BOM	Bill of Materials
Bridgelogix	A software used at receiving to confirm the receiving of parts in Baan and to print labels. The system is easier to work in than directly working in Baan
COI	Cube per Order Index: A classification method used to assign locations to products. Assigned locations are based on how frequently an order is picked
ERP-system	Enterprise Resource Planning: Software system that manages and integrates business processes
I/O points	Point where the picking and storing happens in a dynamic storing system
Kardex	A supplier of dynamic storing systems, among others the VLM in this thesis
OEM	Original Equipment Manufacturer: A company that manufactures parts and subsystems that may be used in another companies end-product
Multiple command	In a VLM, bins are often retrieved for multiple items in one order without being able to store parts in-between. This is called multiple command
Parts	Another word for products that is used in this thesis to enable distinguishing between end-products and products used in the end-products
PowerPick	The software Kardex Remstar provides to manage processes within the dynamic storing systems
Superfluous Bins	This wording is used in this thesis to define that there are multiple bins in use for the same part and containing free storage space
VLM	Vertical Lift Module. A vertically built dynamic storing system

1. Introduction

1.1 Company information

Benchmark Electronics, Inc. was in 1979 founded in Clute, Texas, and has plants all over the world. Benchmark currently has eighteen locations, of which two are located in Europe. This research was performed at the location in Almelo, The Netherlands. The plant in Almelo has grown a lot in the last few years and currently employs around 550 people.

Benchmark is a global contract electronics manufacturer and delivers parts and subassemblies to companies all over the world. Key market sectors Benchmark is serving includes industrial controls, defense & aerospace, test & instrumentation, and medical. The site in Almelo focusses on design engineering and manufacturing. Currently, the company serves as a supplier for around thirteen customers, including large companies such as Thales, ASML and Airbus. The products Benchmark produces for their customers are rather complex and exist of many parts. Besides that, the operations the company delivers are very customer oriented, causing every customer to need a separate managed operation. To manage this, every customer has their own program manager and their own planners and purchasers. Partly caused by the diversity of customers, there are a few major departments within the company that can be distinguished. These departments are known as the SMD-lines (Surface-Mounting-Device), HMT-department (Hand-Mounting), BB-department (BoxBuild) and the CR (Clean Room).

Figure 1: Location Benchmark Electronics, Inc. in the Netherlands

1.2 The problem

The reason for this study is that the warehouse of Benchmark becomes overfull. In the past few years, the company went through a major growth. This growth has its upsides and its downsides, of which a downside is the increasing number of parts that arrives at the company every day. The space in the warehouse of the company was not expanded simultaneously with the growth, causing the warehouse to become fuller and fuller. While the number of parts grew, the physical space did not, causing a physical storage problem. The company acknowledges this problem, but does not want to physically expand their warehouse at the moment. Therefore, this study focusses on presenting a way to store all incoming goods again, without increasing the warehouse in m2.

1.3 Motivation for investigation

In this thesis, the management problem solving method (MPSM) from the book Geen Probleem is applied. This is a systematic approach for solving a managerial problem. In this approach, there are seven phases. The first phase is to identify the core problem (Heerkens & van Winden, 2012), which is one of the problems in the problem cluster. The core problem is identified during preliminary investigation (marked orange in figure 5). To see how the core problem was chosen as the best problem to solve, a discussion about the possible core problems can be found in appendix 10.1. The rest of this thesis walks through the remaining six phases in the background. Besides that, a PDCA-cycle will be applied to monitor the improvements which is preferred within Kaizen (see chapter 2 for explanation).

Figure 2: Problem cluster

The company wants to optimize the use of space within the warehouse. This helps the company to deal with future demand and a growing number of incoming materials. The problem this project focusses on is that one type of part is often divided over multiple bins in the VLM of the main warehouse (Kardex ZKDX1001). This is declared to be a problem since these bins are rarely fully filled, and thereby occupy a superfluous number of storing locations. Two factors will be used in this project to verify if the superfluous space in use in Kardex ZKDX1001 is eliminated. Space within a bin in the VLM is called superfluous if the bin has free storage space available[1].

The factors that are used to determine the extent to which the amount of superfluous space reduces are:

1. The number of bins in use in the Kardex ZKDX1001
2. The number of part types in the Kardex ZKDX1001

[1] Superfluous bins: Bins are called superfluous in this thesis, if there are multiple bins of the same part containing free storage space

1.3.1 Core problem

After specifying the core problem with a norm, the problem is described as follows:

Around 20 percent of the bins in the VLM systems of the main warehouse is in use by one part type that is assigned to more than two locations that are not fully filled, causing superfluous space of the VLM to be filled

This percentage was determined by dividing the number of bins (factor 1) by the number of part types (factor 2) in Kardex ZKDX1001. The number of bins containing part types that occupy more than two bins turned out to be approximately 20 percent. The reason for a maximum of two bins is explained below.

1.3.2 Goal of the project

The goal of this project is to identify the optimal space efficiency solution for Benchmark to be able to solve the core problem. To achieve this goal, this study will present an answer to the following question:

How can the superfluous space in use by parts stored in more than two bins in Kardex ZKDX1001 at Benchmark Electronics, Inc., be reduced from 9% to 0%?

The norm of 9% in the goal described above is calculated based on a maximum number of two bins per part type. This maximum is deliberated with Benchmark. Benchmark thinks that in a perfect world the number of bins per part type would always be one. However, some parts may need to be stored in a second bin due to for example not fitting in one bin occasionally. Taking this into account, Benchmark deliberated that the norm of maximum bins per part will for now be set to two. The 9% in the research goal could then be reduced to 0%. In this case 879 of the 9755 occupied bins will be released, which is explained below.

Calculating the percentage of superfluous space in use

To be able to calculate the percentage of superfluous space in use, the number of bins in use by a specific part type has to be known. Table 1 shows the total number of bins and the number of part types, with the corresponding number of bins per part in the Kardex.

By dividing the total number of bins (column 2) by the number of bins for one part type (column 1), the total number of part types (column 3) can be calculated. The three variables together can be used to calculate the possible bin reduction. In this case, the maximum number of bins for one part type is set to two, which leads to the following calculation:

Possible bin reduction = Total number of bins – (2 * total number of part types)

In the calculation above, two bins are distracted from the total number of bins for one part. The “2” in the calculation makes sure there is a maximum of two bins for a specific part. In the case of three bins for one part (from column one), 1173 is subtracted with two times 391, returning (1173 – (2*391)) = 391 bins to be superfluous.

The summation of the calculation for 3 to 15 bins from column one results in 879 superfluous bins, which is a reduction of (879/9761) = 9%. When superfluous bins would be released, around 9% of all locations in Kardex ZKDX1001 could be released.

Table 1: Number of bins and number of part types in Kardex ZKDX1001; Data is exported from PowerPick

Number of bins (locations) for a specific part type	*Total number of bins*	*Total number of part types*
1	4928	4928
2	2832	1416
3	1173	391
4	392	98
5	220	44
6	84	14
7	28	4
8	40	5
11	22	2
12	12	1
15	30	2
Total	9761	6905

Benchmark could in the future want to adjust the maximum number of bins for a part type. In this case, the “2” in the calculation can be replaced with the new maximum number of bins for a part type.

1.4 Project approach

1.4.1 How to achieve the goal

The goal of this project will be achieved by performing several actions. Data was investigated in section 1.3 first, to quantify the problem and determine the goal of the study. In the upcoming chapters, the current situation within Kardex ZKDX1001 is outlined to get a clear picture of it. Since the current situation may change when the solution is implemented, and to find out where the current situation may change, a process flowchart is used to depict the current receiving and storing process and the receiving and storing process after implementation of the solution. A Pareto analysis will be applied to find out if there are customers who influence the problem more than others. The outcome of this analysis is used to narrow the focus of this research to fewer customers.

Thereafter, possibilities to improve the current situation are developed by conducting literature research, by discussing with people from different sections of the company and by properly thinking and walking through the warehouse myself. The developed possibilities are discussed with the company and an implementation plan of the preferred solution is provided. Lastly, a conclusion, recommendations, and limitations of the study are presented.

1.4.2 Deliverables

To be able to provide Benchmark sufficient information about how to achieve the research goal in 1.3, the following deliverables will be provided:

1. Quantification of the problem
2. Possibilities to reduce the number of unnecessary bins from 9% to 0%
3. Possibilities to assign parts to a location in the VLM system
4. Possibilities to distinguish parts
5. Discussion of all possibilities
6. Plan for implementation of the preferred solution
7. Conclusion, recommendations and limitations

1.4.3 Research questions

Research questions are defined that help to reach the goal of this project. Sub-questions are defined to reach a more specific direction in the research. All questions will be answered in this thesis.

1) What does the current situation look like?

a. How are parts received, stored and picked in Kardex ZKDX1001?
b. How are parts assigned to a storage location in Kardex ZKDX1001?
c. Why does the current storing method cause parts to be stored in more than two bins?
d. Could parts be distinguished within the problem or the solution if necessary?
e. To what extend is the current storing method sufficient for all parts stored in Kardex ZKDX1001?

By answering the questions above, the cause of superfluous space will be investigated. Besides, finding out the necessity of the current storing procedures can declare that improvements in the storing procedure reduces the amount of superfluous space.

2) What alternative methods can reduce the number of superfluous bins in Kardex ZKDX1001, while maintaining efficiency?

a. What alternative FIFO storing methods do there exist for Vertical Lift Modules?
b. How can the optimal storage assignment method be determined?
c. What classification possibilities are there to be able to classify parts?

Answering these questions discovers which improvements concerning storage possibilities there exist in literature databases. These possibilities will be assessed on their applicability.

3) What does Benchmark think about the alternatives to optimize use of space in the Kardex?

a. What are the requirements of the solution, according to the company
b. What are the pros and cons of the current method?
c. What are the pros and cons of alternative methods?
d. What do employees think of the alternative methods?
e. What are the expected results when applying the preferred method?

In this question, the requirements of Benchmark are answered and the optimal solution is studied by looking to pros and cons of every presented method. Besides, the opinion of employees is taken into account and the expected results of the preferred method are established.

4) How can the preferred method be implemented at Benchmark?
This question is answered to enable the optimal solution to become successful.

Preferences of the company

To be able to take into account the opinion of warehouse employees, they are asked about their view on the gathered possibilities for solving the problem. These opinions together with literature research and common sense returns recommendations for improvement at the end of the project. Since the last two weeks of this research the company was closed, some people were not able to give their opinion. Which may slightly bias the results.

Conclusion

In this chapter, the core problem is quantified by determining the possible reduction of superfluous space with a maximum of two bins for one part type. The research questions and project approach of this thesis are presented to enable the solving of the core problem. To see what theories are used in the continuing of this thesis, the theoretical framework is explained in chapter 2.

2. Theoretical framework

A specific problem can be solved by providing a well-structured approach with a theoretical framework. To be able to improve the current situation, an approach is needed as a guideline. To clarify this approach, the theoretical framework that is maintained in this thesis will be elaborated in this chapter. This includes theories the company is already pursuing as well.

2.1 Applied theories during research

The methods that are applied in this research are explained and discussed here. This serves as a foundation for the choice that a PDCA-cycle, a Pareto analysis and an Analytic Hierarchy Process are applied. Hereby the question of how to get an optimal solution is answered.

Benchmark is continuously working on improving processes within the company to achieve the best products for their customers. The method that Benchmark applies to achieve continuous improvement is Kaizen, which is a method to improve processes within a company. One element of Kaizen is a PDCA-cycle. This cycle can be applied to enable making improvements in the storing problem, with Kaizen in mind.

PDCA-cycles

Benchmark wants to make improvements based on the theory Kaizen, also described as "continuous improvement" (Berger, 1997). The best practice to reach continuous improvements is by making small improvement steps. Plan-Do-Check-Act (PDCA) cycles are a tool to keep track of these improvements (see figure 3). In these cycles, Plan stands for description of the problem and suggested improvement, Do is the implementation of the improvement, Check is to check if the intended results are reached and Act is to transform the implementation into a routine ("Plan-Do-Check-Act," 2006).

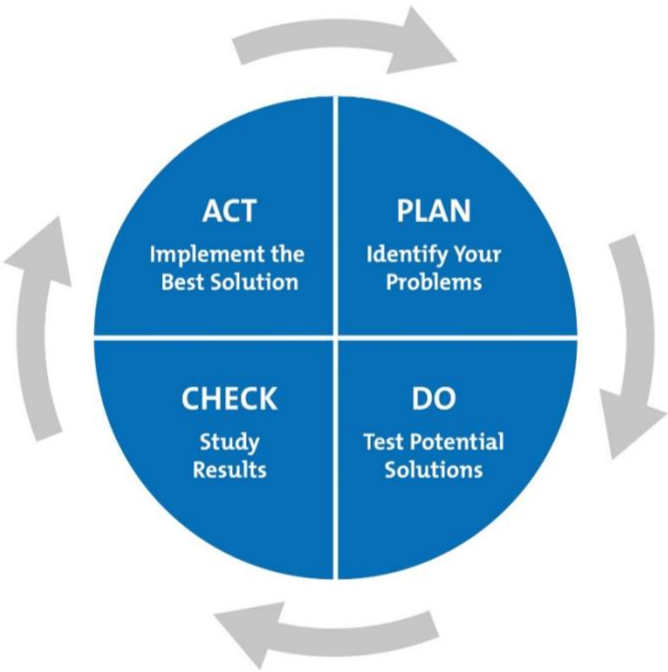


Figure 3: Plan-Do-Check-Act (PDCA). Reprinted from MindTools website, Retrieved from https://www.mindtools.com/pages/article/newPPM_89.htm

The current problem at the Benchmark warehouse is caused by more than one constraint, which is further explained in section 4.1 and appendix 10.1. Tackling all constraints at once would become complicated. Hence, one constraint is improvement is this thesis.

Pareto analysis

In section 3.3, a Pareto analysis is performed to simplify data analysis and at the same time keeping reliability high. Since approximately 20% of the causers is responsible for 80% of the problem, tackling these 20% can have a significant influence on the outcome of the solution.

Pareto analysis is based on the observation that economic wealth and results from operations are not equally distributed. Some inputs can contribute more than others, meaning a pattern of imbalance is observed. When applying Pareto, improvements in the 20% of causers ,who are responsible for around 80% of the negative effects, can compensate for the rest of the causers. Therefore the method is also known as the 80/20 rule (Powell & Sammut-Bonnici, 2014). Applying the Pareto analysis could result in a solution that is only applicable for 20% of the causers. At the end of this thesis, evaluation can reveal if the solution is applicable for the other 80% too.

Analytic Hierarchy Process

In this thesis, AHP will be applied to choose the best alternative classification method for the system when the company decides to implement the class-based storage assignment method. The AHP is chosen, because a previous thesis that was executed at the company about the optimal storage assignment method applied this method to make a decision, with approval of the company. Besides, literature shows it is a sufficient method for decision making. The AHP will be applied in section 6.4.

The Analytic Hierarchy Process, in literature known as AHP, is a multicriteria approach for decision making. Factors are arranged into a hierarchic structure in this process. The most important factors that have to be taken into consideration when making a decision will be included. The hierarchy is built up with the overall goal on top, underneath the criteria, eventually sub-criteria below the criteria, and at the bottom the alternatives. In figure 4 an example of the AHP is visualized. In the model, weights are given to each (sub)criteria. The weights are calculated for each (sub)criteria, by which a score for each alternative can be generated. The highest score that is generated implies the best alternative (Saaty, 1990).

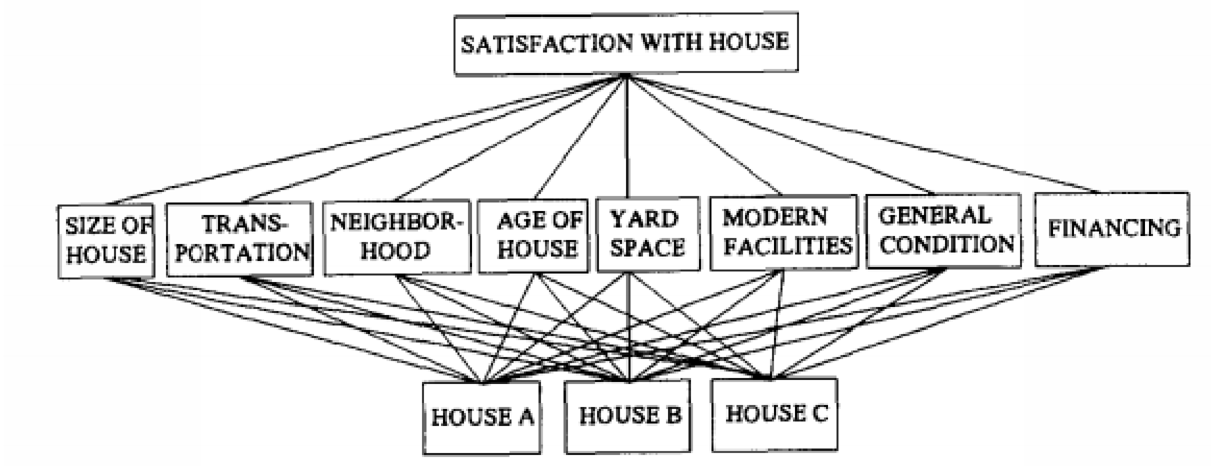


Figure 4: Decomposition of the problem into a hierarchy. Reprinted from "How to make a decision: The analytic hierarchy process" by T.L. Saaty, 1990, European Journal of Operational Research Vol. 48, Issue 1

2.2 Applied theory to assign parts to a location

Benchmark is currently applying the First in First out method to assign stock to a location. To find out what this method implies and what other possibilities there exist to assign stock, the First in First out method was studied. Question 1c is hereby partly answered.

First in First out

The company is trying to achieve First in First out (FIFO) picking of parts to ensure the quality of products and subassemblies. Since the necessity of the company to apply FIFO is not established, this theory will be taken into doubt in this thesis.

First in First out (FIFO) is known as a memory methodology in inventory. This method is getting the product that came in first as inventory, first out of the warehouse for production. The method should ensure the oldest product to always be used first. Many companies apply this method to be able to ensure quality to the highest.

According to Janssen, Claus, and Sauer (2016), there are three inventory issue policies. These policies are FIFO, Last in First out (LIFO) and Random Retrieval (RR). The FIFO policy is always optimal (Nahmias, as cited in Janssen et al.), but the relevance of the policies is different, depending on the situation of the company. In healthcare FIFO would apply best, whereas LIFO or a combination of FIFO and LIFO would be more relevant in food retail for example (Janssen et al., 2016). For an item with fixed life, issuing the oldest items first is the best method to minimize expected outdating. LIFO issuing is more convenient when the user choses the issuing policy. According to literature, customers typically prefer LIFO (Silver, as cited in Janssen et al.). For perishable products this is not desired, due to their fixed lifetime. Next to FIFO and LIFO, products can be picked at random. Random retrieval does not take into account the age of a product at all. The article of Janssen et al. (2016), tells RR is most applicable for products with infinite lifetime. The main conclusion that can be drawn is that customers have most influence on the choice of retrieving products. Altogether, the customer is the one who is paying and using the product.

Since parts are customer specific at Benchmark, it is not recommended to use LIFO. Using LIFO would make the state of end products more diverse, which is not what the customer wants. The quality of products has to be equal as possible, with less chance on picking old parts. Now LIFO already falls off, only FIFO and random picking are left.

Conclusion

The theoretical framework serves as a guideline for research. The methods that are applied in this study are outlined, to give an impression of how these methods work. The thesis walks through one PDCA-cycle to solve the chosen cause of the core problem. The Pareto analysis is applied in chapter 3 to simplify data while keeping accuracy high. The AHP is applied in chapter 6 to be able to provide the best classification method to Benchmark. And last, the FIFO method was explained and taken into doubt. Alternatives for this method are provided and further investigated in chapter 4. The theory in this chapter altogether helps to understand the continuing of this study.

3. Current situation

To be able to improve the operational strategy, it is necessary to investigate the current situation. The provided information focusses on identifying the current situation in the main warehouse of Benchmark and of Kardex ZKDX1001 in specific. The information in this chapter provides insight in the current receiving, storing and picking processes. These processes are subject to change when improvements are applied to optimize utilization of space. Next to that this information serves as input for the PDCA-cycle in chapter 4. First, to give a little impression of the warehousing circumstances, the warehouse in general is explained.

3.1 Current warehouses

The products and subassemblies Benchmark produces consist of a great variety of parts. All these parts arriving at Benchmark, first have to be stored in the warehouse. There are multiple warehouses within Benchmark, of which the major two are known as the main warehouse and the SMD-warehouse. The SMD-warehouse is used for storing SMD-reels. These reels are used for manufacturing in the printed circuit board assembly hall. Most of the parts in the SMD-warehouse are needed once in a couple of years, because demand of the customer is recurrent and can to a certain extend be forecasted. The main warehouse is storing mostly durable parts for which the necessity of FIFO is not established. The scope of this project focusses on the main warehouse.

Main warehouse

Parts that are stored outside the main warehouse are quite dependent on their lifetimes. Parts and products that are stored inside the main warehouse on the other hand, have a far more flexible lifetime. Incoming parts and finished products in the main warehouse are stored on shelves or in the VLM systems.

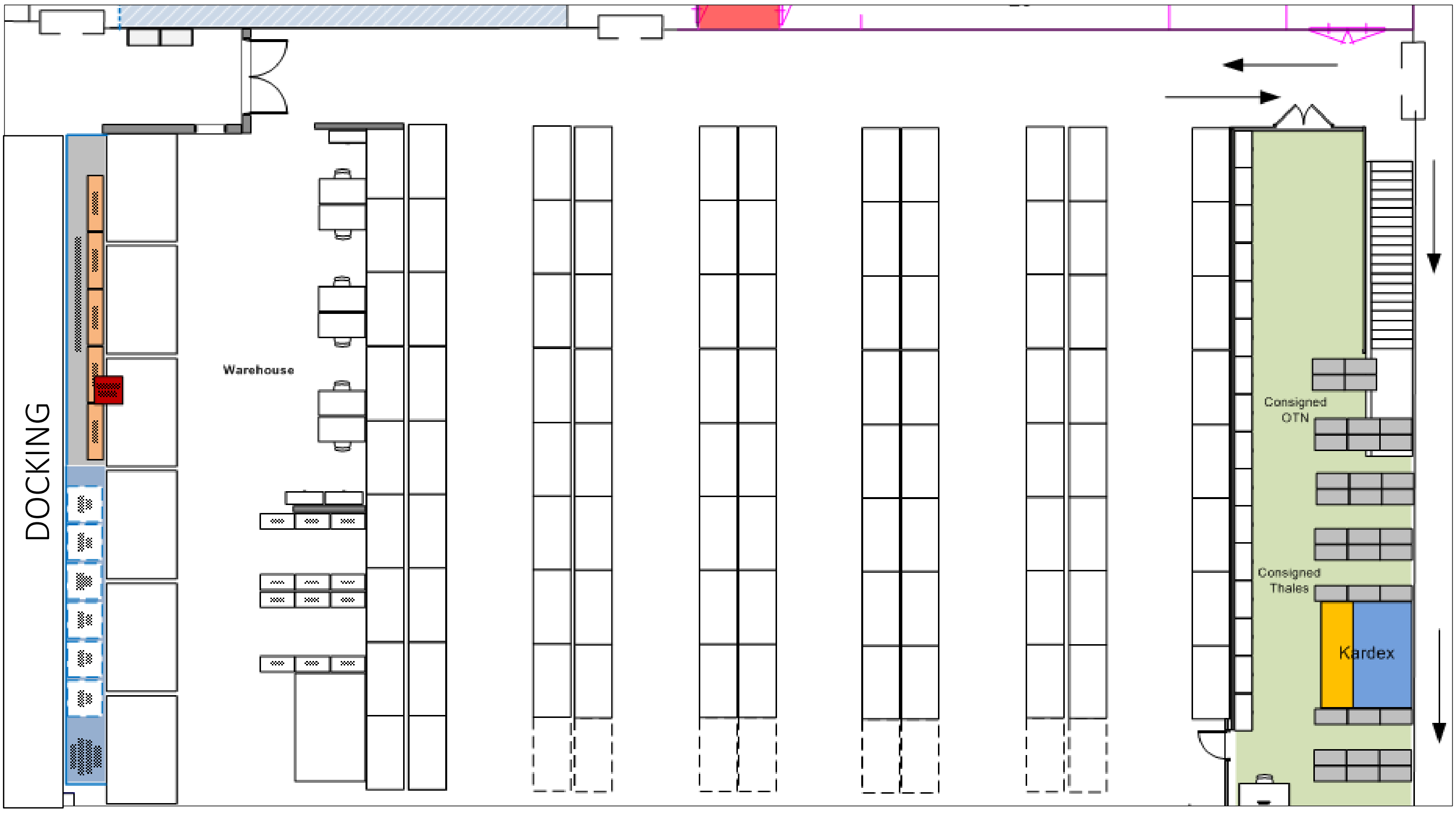


Figure 5: Floorplan of main warehouse at Benchmark

Kardex ZKDX1001

Most of the incoming parts are stored in the VLM systems, located on the left side of the warehouse in the floorplan (figure 5). They arrive from the docking department, located outside the warehouse on the backside of the VLM systems ("docking"). Finished products or parts that cannot be stored in the VLM are mostly stored in the shelves (all white rectangles in the middle of the floorplan).

Figure 6: Kardex ZKDX1001

In figure 6, a few of the VLM systems are depicted. All parts that have to be stored in the VLM systems are placed inside a bin at the docking department of the warehouse. With help of the display hanging on the front edge of the VLM, the right plateau can be requested and bins can be placed or parts can be picked.

The company currently has seven VLM systems in use in their main warehouse. All VLM systems in the main warehouse are together known as ZKDX1001. This name is used in all software tools the company uses. Around the end of May 2018, a new VLM was placed in the main warehouse to temporarily solve the problem of not being able to store incoming parts. Since demand is still growing and space in the VLM systems is not always used efficiently, the warehouse manager thinks the space problem will probably return within half a year.

Benchmark programmed the ZKDX1001 to store parts according to the FIFO method, meaning that the parts that came in first will also be picked first. By conducting this method, Benchmark is able to serve their customers with products containing parts that are as new as possible. To be able to achieve FIFO, identical parts that arrived on a different moment are stored in an empty bin in the VLM systems. For this reason, bins are not always fully filled while particular parts occupy multiple locations. The consequence of this method is that some parts occupy much superfluous space due to their number of storing locations.

3.2 Storage assignment in Kardex ZKDX1001

Usually the movements of a product in a warehouse are divided in several processes: receiving, storing, order picking and shipping (Li, Moghaddam, & Nof, 2016). Just like an average warehouse, movements of the parts at Benchmark can be divided in these four processes. Normally, all four warehousing processes together take around two days.

This chapter focusses on the receiving, storing, and picking processes, since only these three processes effect the problem of superfluous space in the VLM. To give a clear view of how the receiving, storing, and picking of parts proceeds within Benchmark, all three activities will be outlined. The explanation mostly focusses on Kardex ZKDX1001, since this represents the scope of the project. A visual overview of how parts get a location assigned in the system is provided in the process flowchart in figure 11.

1) Receiving

Warehouse management starts when parts arrive at the company. Trucks with parts arrive at the docking department every day. The trucks are unloaded and the parts from the trucks are placed at the docking part of the warehouse. To be able to discover if and when parts were received afterwards, the waybills of all boxes are scanned and kept record of. The parts then wait until they are confirmed as received in the ERP-system Baan. Before this happens, parts have to be checked on their quantity and material code. Most parts are received in cardboard boxes or plastic bags, so that individual parts like screws stay together. When the wrong parts or wrong quantities have been received, parts are transferred to inspection for a second check. If received parts are ready to be stored, they will be placed in a bin and put on a storage cart.

When the check is positive, parts receive a label with information (see figure 7). The information on the label among others shows the material number, MBA-number, and the warehouse location (e.g. Kardex ZKDX1001). The labels are printed with a software called "Bridgelogix".

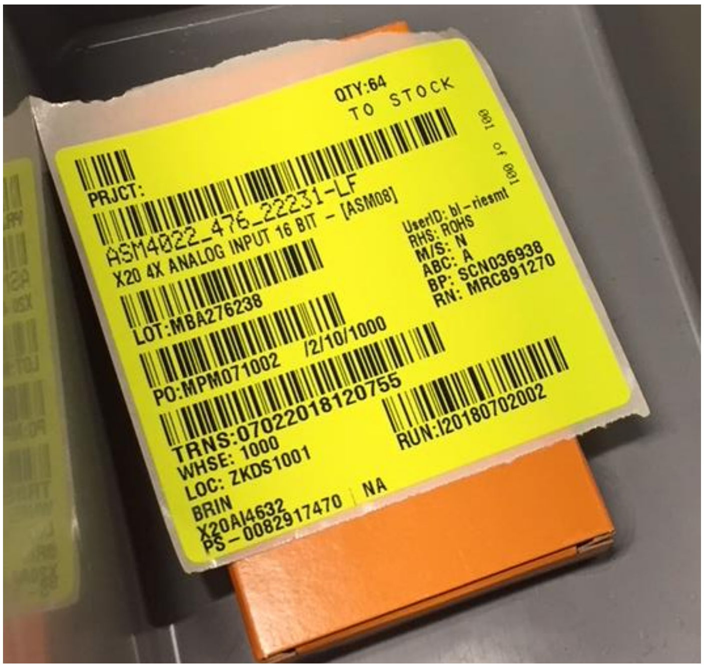


Figure 7: Label with corresponding MBA-number

For every orderline on a delivered order, three labels are printed. One for the bin the parts are placed in, one to put on the delivery note and one for the warehouse employees to let them know which parts have to be stored in the VLM of the main warehouse. After confirming all parts from one delivered order in Baan, the receiving process can continue. The parts will be placed into the bin size that is most applicable. In this case, applicable means that all parts from one orderline fit in one bin with little free space in the bin as possible.

Bin types

There are six different bin sizes. The applicable size depends on the dimensions of the parts altogether. The warehouse employees working in the docking department determine the applicable size of bin for the parts. They always try to make sure that parts exactly fit into one bin, with leaving little free space as possible. The following sizes of bins are available (dimensions attached):

Table 2: Dimensions of storage bins in use at Benchmark

	Length	Width	Height	CM3
B001	200	148	117	3463200
B002	300	200	170	10200000
B003	400	300	220	26400000
B004	600	400	320	76800000
B005	600	400	120	28800000
B006	555	90	80	3996000

In exceptional cases (e.g. when all parts together do not fit within one bin) two bins may be used. It might also occur that a particular size of bin is not available, because all bins of this size are already in use. If this is the case, other bin sizes have to be used. Nevertheless, warehouse employees always make sure that only parts for a particular MBA-number are placed within one bin to achieve FIFO picking.

Batching

After putting all parts from one delivery note into bins, the bins need to be batched in order to connect bins to a location in the VLM. This is executed with software provided by Kardex Remstar, called PowerPick. PowerPick is installed to automatically search for empty bins in Kardex ZKDX1001. When all bins from one storage cart are batched, the full cart will be transferred to the main warehouse. PowerPick labels the carts in the stage between receiving and storing as “carts to be stored”. In Baan this is indicated with “ZKDS1001”.

Briefly described

In short, the receiving process for parts that are stored in Kardex ZKDX1001 consists of:

1. Unpacking received orders
2. Checking orders
3. Processing received orders in Bridgelogix and Baan
4. Printing labels and placing parts with corresponding label in appropriate, empty bin
5. Batching bins to assign a location to the parts in Kardex ZKDX1001
6. Transfer storage cart to Kardex ZKDX1001 in the main warehouse

2) Storing

All bins on a storage cart have to be confirmed in PowerPick before storing can start. PowerPick shows all carts in location ZKDS1001, the stage between batching and storing. When a cart is confirmed in PowerPick, the display of the VLM (see figure 8) shows all material numbers of the parts (ASM4022_438_31308-LF) from the confirmed cart consecutively, the location the bin has to get in the Kardex (SH03-003-06-02), the quantity that has to be stored (5), and the bin the parts have to be stored in (B001-1009). When one bin has been stored, the following in line will be displayed after the storing is confirmed with a barcode scanner. To minimize mistakes during storing or picking, a display shows the location to store a bin in red (figure 8). Locations are depicted in green when bins are empty.

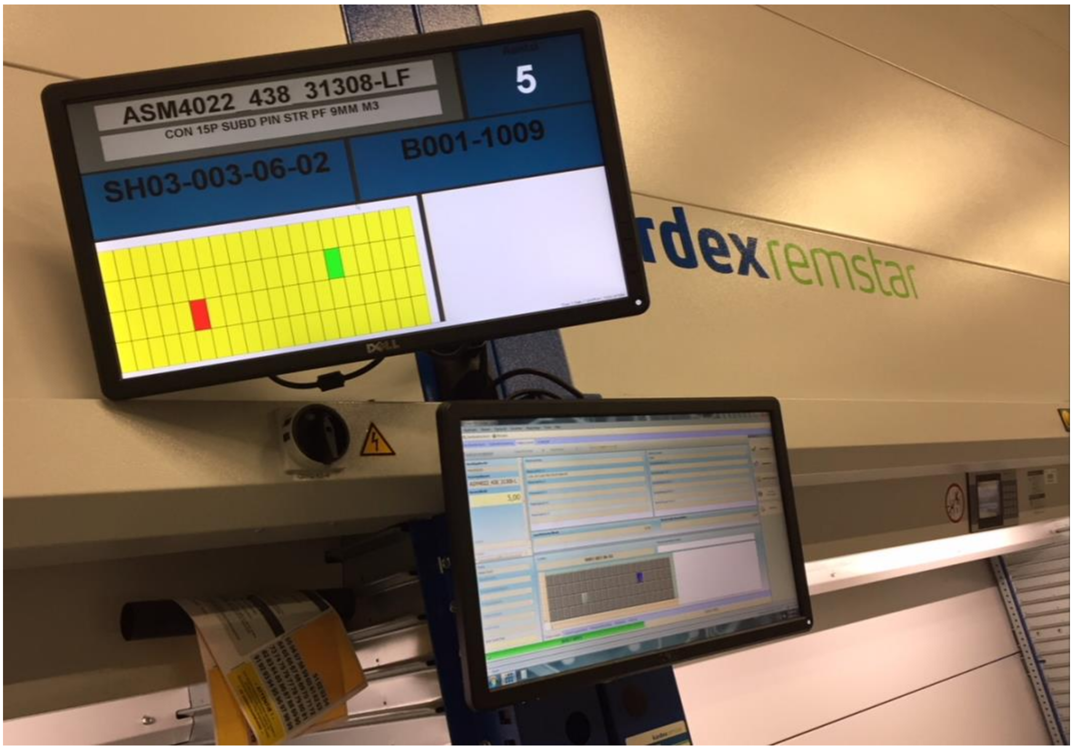


Figure 8: Display Kardex ZKDX1001

To confirm storing, the barcode in the bin has to be scanned (see figure 9). The empty bin that is swapped with the new bin after storing will be transferred to the receiving department again. This means that the storing process influences the number of available bins for a certain bin size in the docking department.

Figure 9: Barcode in bin

Assigning location

The location a bin gets assigned in the VLM depends on the size of the bin. Bins are located in a random empty space on a plateau with corresponding bin sizes. PowerPick searches for these empty locations during the batching of parts. PowerPick only searches on a plateau where bins of the same size are stored. As a result, parts in a B001 bin can only be placed on a plateau with other B001 bins. This is a way to optimize the use of space in the VLM systems. For example, B001 bins are only 11,7 cm high and require less height in the VLM then B003. Placing only B001 bins in one plateau can this way saves room for other plateaus. This would not be possible if the plateau also contained some higher bins.

Briefly described

In short, the storing process for parts that are stored in Kardex ZKDX1001 consists of:

1. Confirm storage cart in PowerPick
2. Store bin that is indicated on display in front of the shuttle
3. Pick empty bin from the location the new bin was stored
4. Confirm the storing by scanning barcode of bin
5. Store next bin that is indicated on display

3) Picking

Before the start of a production process, all parts that are needed are picked at once. This is in most cases done with help of workorders. The workorder tells what parts and attached quantities are needed in the end-product. Powerpick knows where the picker has to pick after confirming the workorder in the software. When the picker starts picking, the VLM automatically transfers the requested plateau with the right bin to the picker. The picker knows the bin he has to pick parts from, based on the information on the display (figure 8), from signs on the requested plateau and from the workorder. Since parts in one bin are all originating from the same batch lot, warehouse employees do not have to think about which parts to pick first from the bin. The picker only has to request the desired plateau the display is showing and pick the right number of parts. However, a disadvantage of storing only one batch lot number into one bin is that the picker might have to pick from multiple bins in different VLM's. As a result, the picker might lose overview of the parts to be picked in order to complete the workorder, according to warehouse employees (Renske, July 26).

To be able to keep picked parts and additional information together after picking, a small paper showing the warehouse the parts came from and the material number of the parts is placed in a transfer box together with the parts (figure 10). What was mentioned by an employee from the operations department is that these small papers easily get lost.

Figure 10: Papers and parts in transfer box

After all parts from one workorder have been picked and placed in a transfer box (figure 10), the transfer boxes are placed on a cart. Full carts can be transferred to the work floor when all parts for the production process are picked. Sometimes workorders require more parts that are stored in other warehouses of the company. Nevertheless, the main warehouse is always the first warehouse where parts for one workorder are picked.

Briefly described

In short, the picking process for parts in Kardex ZKDX1001 consists of:

1. Confirm incoming workorder in Baan
2. Pick the parts from the location the display in front of the VLM is showing
3. Count the parts and put them in a transfer bin
4. Put a paper (see figure 10) with information with the parts that were picked
5. Confirm the picking by scanning the barcode of the bin
6. Pick next parts the display of the VLM is showing

Process flowchart

In this chapter, a process flowchart is used to clarify the current receiving and storing processes. Process flowcharting is a technique to analyze a process and to enable solving of a problem. The idea of a process flowchart is to give an overview of a process with help of figures like rectangles or circles. The flowchart should show core processes and their linkages (Krajewski, Ritzman, & Malhotra, 2013).

In figure 11, the process flowchart for the current situation is presented. The flowchart depicts only the receiving and storing process within Kardex ZKDX1001, because these two activities have influence on the storage location parts get assigned. In chapter 7, a process flowchart is used to clarify the receiving and storing processes when the improvement is implemented.

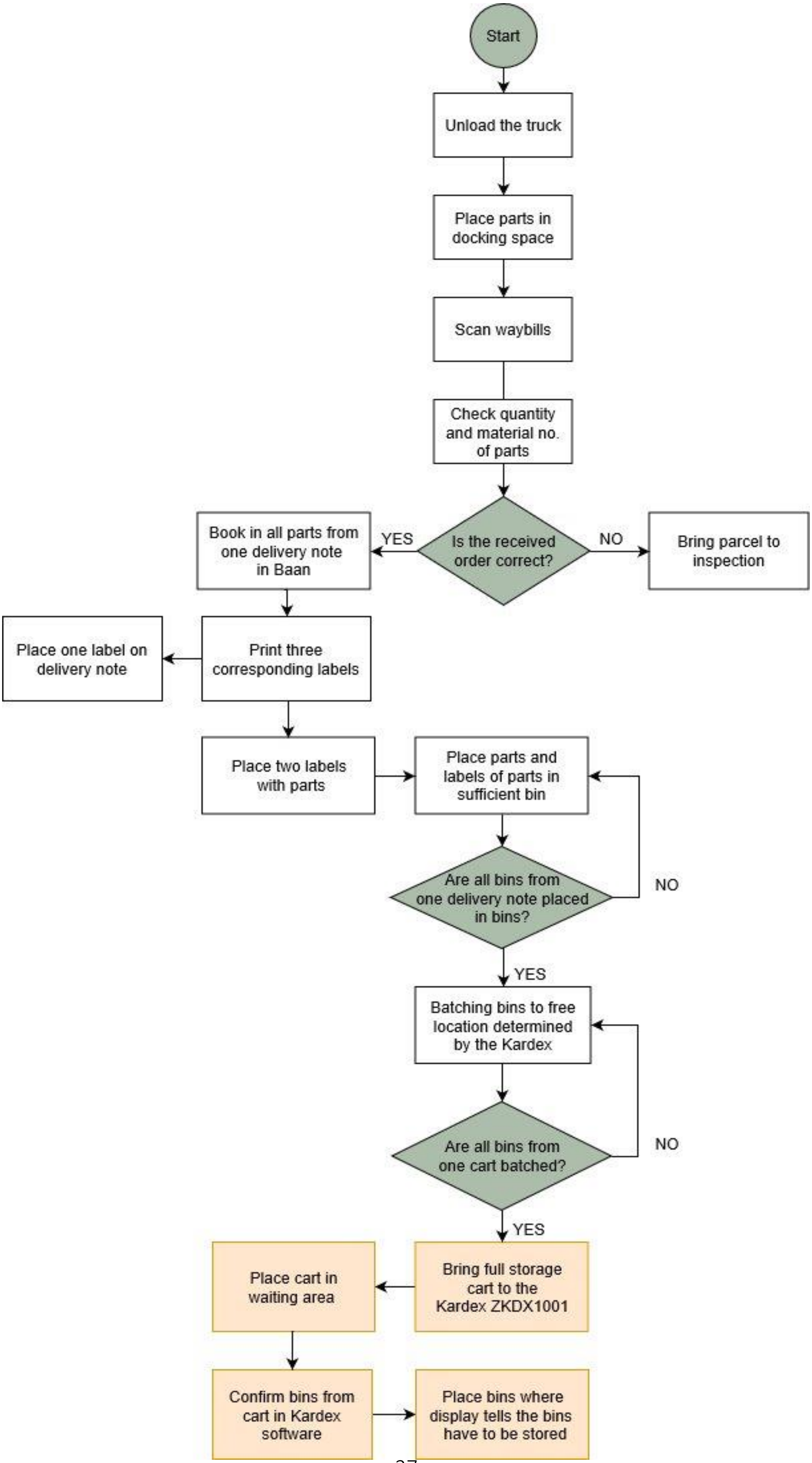


Figure 11: Receiving (white) and storing (orange) at Benchmark Electronics, Inc.

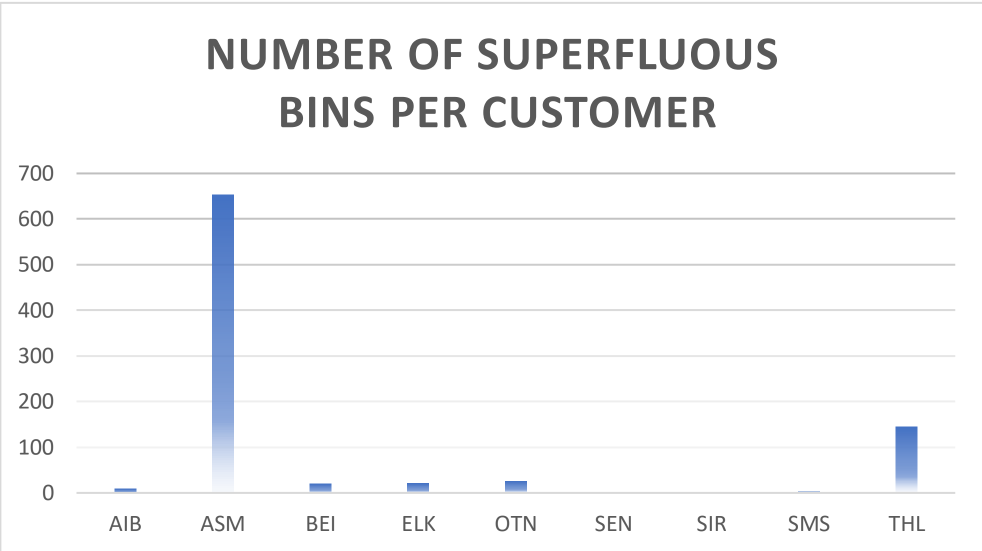
3.3 Space management problem in Kardex ZKDX1001

In section 3.2, the storage assignment method within Kardex ZKDX1001 is clarified. With this information in mind, we zoom in on the problem. The problem is that one type of part is often divided over multiple bins in the VLM and this way occupying an superfluous number of storing locations. In section 1.3, the possible reduction of bins was determined when the maximum number of bins per part type is set to two. This resulted in a required reduction of 879 bins, equal to a reduction of 9% of all location in the Kardex.

The Pareto analysis is applied to see if there are customers that influence the space problem more than others and if so, who these customers are.

3.3.1 Pareto analysis

The Pareto analysis tells that 20% of the causers is responsible for 80% of the effects, as was explained in the theoretical framework (chapter 2). According to data from Kardex ZKDX1001, two customers are responsible for around 90% of the superfluous bins. In graph 1, these two are shown as ASM (ASML) and THL (Thales). This is interesting and the reason that the focus of this study shifts to only these two customers. At the end, evaluation can discover if the solution could be applicable for other customers too.



Graph 1: Sum of unnecessary bins per customer

Conclusion

This chapter described the current situation within the VLM systems in the main warehouse. Explanation of the receiving, storing and picking processes showed that the FIFO way of assigning parts to a location in the VLM influences the amount of superfluous space. Furthermore, a Pareto analysis was applied to be able to simplify data while maintaining accuracy. Finding a solution for the two main causers of the problem can improve the problem significantly. In chapter 4, the necessity of FIFO storing will be studied for these main causers by conducting interviews. First, the Plan step of the PDCA-cycle is performed to identify causes of the superfluous space inside bins and to develop a plan.

4. The PDCA-cycle

In the theoretical framework, the concept Plan-Do-Check-Act cycles was briefly explained. This method picks one of the causes of the problem and attempts to improve it. The focus of the cycle and the Plan of the cycle will be treated in this chapter. After the Do and Check of the cycle, evaluation (Act) can find out if the improvement works for Benchmark.

4.1 Causes of the unnecessary bins

In principle, FIFO picking of parts would not immediately have to mean that identical parts are stored in an superfluous number of bins. Nevertheless, there are two reasons this still occurs. These reasons were established in deliberation with Benchmark. The reasons are:

1. Parts stay in the VLM longer than expected
2. Different MBA-numbers always have to be stored in different bins to reach FIFO

1. Parts stay in the VLM longer than expected

Just in Time is a philosophy and a technique that guides manufacturing companies in the organization and management of processes. This method can help to achieve manufacturing at a high velocity. The method smoothens material flows from the supplier to the customer (Hong-Mo, n.d.). Just in Time suggests parts to arrive just before the start of production.

Benchmark is trying to achieve Just in Time incoming of parts. In a perfect situation, this would mean that parts stay in the warehouse for a couple of days and then leave to be used in production. One bin would generally be enough to store all parts. In exceptional cases, two bins are necessary when production time is long and the time between demand of two products is short. At the moment, this is not the case (see table 3). Of the total bins in use in Kardex ZKDX1001 (9761), 1678 bins (17% of the total) are in use for more than half a year. Moreover, 2572 (26%) of the bins are occupied by parts that do not have demand.

Table 3: Number of locations and quantity of parts in Kardex ZKDX1001 (total versus without demand) Data from 16 July

Aging (days)	Total number of bins	Bins containing parts with no demand	Total quantity of parts	Total quantity of parts with no demand
1 - 10	3781	98	9.021.256	8.101.783
11 - 30	1991	223	893.026	65.788
31 - 60	811	204	528.240	127.237
61 - 90	386	171	480.631	310.906
91 - 180	1091	550	932.665	135.672
180 - 360	1678	1324	5.401.477	1.994.359
> 360	2	2	4	4
Total	9761	2572	17.258.270	10.735.749

2. Different MBA-numbers always have to be stored in different bins to reach FIFO

The percentage of superfluous bins in use in Kardex ZKDX1001 is 9% of the total bins. All these parts in the VLM are generalized as required to be picked based on batch lot number. This number is recognized by the corresponding MBA-number. The oldest MBA-numbers are always picked first.

Assigning MBA-numbers

The MBA-number of a part is assigned to parts during batching. According to the warehouse manager, there are three reasons for difference in the MBA-number of identical parts. Since Benchmark acknowledges this as the causes for difference in MBA-numbers, these three reasons will be outlined and studied:
1) Identical parts arrive on a different moment
2) Identical parts arrive on the same moment in a different batch lot, and
3) Identical parts with a different material number

1) Identical parts arrive on a different moment

MBA-numbers are assigned to parts during batching in the receiving stage. A logical consequence is that identical parts that arrive on a different moment, receive a different MBA-number. When demand is regular and production processes occur often, parts also arrive often in case of Just in Time purchasing. If production processes would always start on the planned moment, this would not be a problem because parts then stay in the warehouse for only a short period. By the time a new batch arrives, the old batch will almost or already be used in production and the number of bins stays low. Since this is not the case, the number of bins for identical parts arriving on a different moment accumulates.

2) Identical parts arrive on the same moment in a different batch lot

Benchmark thinks it is important to know in what batch lot the parts arrived. The supplier indicates the batch lot number of parts, by which Benchmark is able to trace the batch lot parts came from. This can be helpful in retrieving the reason for possible problems that occur in the production process at the supplier or at Benchmark, but also causes the number of bins for identical parts to accumulate.

3) Identical parts with a different material number

Some products Benchmark produces change in BOM during the year. After this change, the customer demands the newer version of a product and together with that the newer versions of parts. These new versions of parts can be the same as older versions, with only a new material number as difference. Since orders are picked based on the material numbers in a BOM, parts with old material numbers stay in the warehouse and new versions will be picked. The difference in versions of one part can be recognized by the material number of the part. This material number influences the MBA-number assigned to parts and therefore causes the number of bins for the same parts (but of a different version) to accumulate.

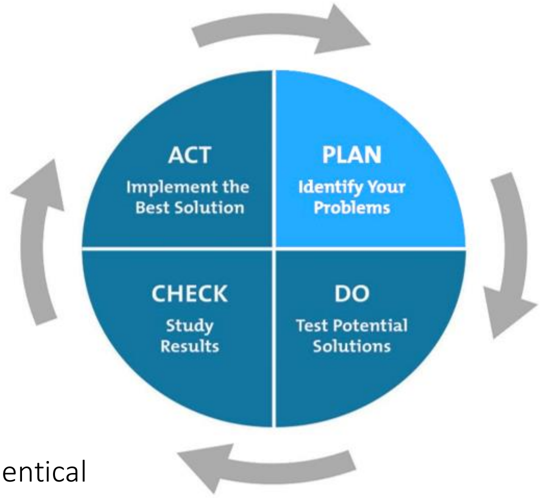
The warehouse manager indicated in a conversation that he thinks this is a relatively large contributor to the problem of superfluous bins in the VLM. Though a quick look into the number of versions per part in Kardex ZKDX1001 showed no significant number of parts with multiple versions. For this reason, identical parts of different versions will be treated as different parts in the continuing of this thesis.

4.2 Choosing the focus of the PDCA-cycle

The amount of time that parts are stored in the VLM systems is partly influenced by purchasing dates and purchasing quantities. During preliminary investigation, the choice has been made to not focus on Just in Time incoming of parts (see appendix 10.1). However, since this is an important influencer of the space management problem, improving Just in Time incoming of parts is recommended to study in the future (see chapter 9).

The remaining cause is the assignment of identical parts with a different MBA-number to an individual location in Kardex ZKDX1001. This issue will be approached in the Plan of the PDCA-cycle in the next section. The gathered information in the Plan will tell for which of the different types of assigning MBA-numbers, placement in a different bin is required. In the Plan, the necessity of FIFO-storing for the two first categories from the previous section is studied. The third type is not taken into consideration, since these parts are considered to be different parts in this thesis.

4.3 Plan: Identification of the problem



In this section, the Plan of the cycle will be performed. This is the identification of the chosen cause. Every MBA-number is currently generalized as needing to be picked FIFO and consequently to be stored in an individual bin. Below the necessity of this procedure is discussed for the two customers identified in the Pareto analysis.

The following three causes for difference in MBA-numbers of identical parts were established in the previous section:

1) Identical parts arrive on a different moment
2) Identical parts arrive on the same moment in a different batch lot
3) Identical parts with a different material number

The first two causes are presented to the program managers of the two customers, to discuss for which of the purposes placement in different bins is required. The last cause, identical parts of other versions, is not discussed since these parts are considered to be different parts.

4.3.1 Investigating problem: Necessity of FIFO storing

The place a bin is stored in the VLM system depends on the MBA-number of the parts in a bin. The reason this method is maintained is to achieve the delivery of products with an equal quality of parts. Moreover, it is used to prevent having one product that contains very old parts and the other with very new ones. Benchmark is currently applying this method to all parts in the warehouse, but the necessity of this method has not been established.

According to conversations with planners, the necessity of storing every MBA-number in a different bin in Kardex ZKDX1001 is low for many parts. This statement has to be verified to be able to quantify the number of parts for which FIFO picking is not particularly necessary. Talking to program managers from ASML and Thales about this procedure gave the required information. Interviews with Program Manager of ASML and Thales leaded to the following findings about the necessity of FIFO storing:

ASML

According to Marc Kunst, Program Manager of ASML, most of the parts from customer ASML do not have to be stored FIFO with great necessity. However, parts are preferred to be FIFO picked based on arrival date and batch lot number. He mentioned that only PCBA’s have restricted lifetime, causing the importance of storing PCBA’s FIFO. Almost all PCBA’s are stored in the VLM systems outside the main warehouse. PCBA (parts) that are stored in Kardex ZKDX1001 can be counted on one hand.

All parts from ASML in three or more bins are summed 1495. Of them, 661 are superfluous and could be removed. As a result, around 7% of all bins could be released from Kardex ZKDX1001 only for ASML.

Thales

According to Mark Rikmanspoel, Program Manager of Thales, FIFO picking of every different MBA-number is required. He thinks this way because Thales always wants to be able to retrieve the batch lot of parts. He also thinks that it is not necessary to store every MBA-number a different bin. It is an easy way to recognize the batch lot, but there are other ways to retrieve batch lot numbers too.

All parts from Thales in three or more bins are summed 311. Of them, 145 could be removed. As a result, around 1,5% of all bins could be released from Kardex ZKDX1001 only for Thales.

Conclusion from interviews

In the theoretical framework, the Random Retrieval of parts was provided as an alternative to store parts inside a bin. This is not the best method to pick parts according to the program managers. From the interviews with program managers of customer ASML and Thales, it can be concluded that program managers prefer all parts in the VLM to be stored FIFO. Besides, not every MBA-number has to be stored in a different bin. This information leads to the following criteria for a solution that will be taken into account when developing a plan for the solution:

- For all parts it has to be possible to pick parts FIFO based on the batch lot number (recognized by MBA-number)
- It is not necessary to put every MBA-number in a different bin

4.4 Approaching problem: Developing plan for solution

In section 4.3, interviews and data determined the focus of the solution. In the continuing of the Plan, possibilities to make the number of superfluous bins reduce while keeping the opportunity to apply FIFO have to be studied. A literature review can help in obtaining ideas of how to achieve reduction of superfluous bins without reducing warehouse efficiency and while maintaining optimal use of space. The literature review is outlined in chapter 5.

Initial possibilities for how to achieve bin reduction are listed below. These initial possibilities were established in deliberation with the operations department of Benchmark.
The three possibilities are:

1) Reducing the number of bins per part by placing identical parts in fewer bins, with FIFO picking based on MBA-number
2) Reducing the number of bins by placing different parts in fewer bins, with FIFO picking based on MBA-number
3) Alternative FIFO storing methods for in Kardex ZKDX1001

For option three, a literature study will be performed in chapter 5 to find out alternative FIFO storing methods. The other two possibilities are alternatives that can already be applied. These two possibilities can be applied in two ways:

- Placing parts in occupied bins in the storing stage
- Placing parts in occupied bins by relocating parts once in a few weeks

These options to put possibilities 1 and 2 into practice are established in deliberation with Benchmark.

Remarks

According to the warehouse manager, placing parts in occupied bins in the storing stage will take a lot of time and is not efficient. He believes that if parts have to be stored in a bin that is already located in the VLM, warehouse employees have to conduct more work and inefficiency of the receiving process increases. To prevent reducing efficiency, optimization possibilities are studied in the literature research by investigating storage assignment methods.

Conclusion

This chapter identified that the current method to store every MBA-number in a different bin is not optimal. It is clear that the assignment of maximum one MBA-number to an individual bin is one of the main causes for having a superfluous number of bins in use in Kardex ZKDX1001. Two criteria for reducing the number of superfluous bins were established: For all parts it has to be possible to pick FIFO based on MBA-number and it is not necessary to put every MBA-number in a different bin. The literature review in chapter 5 will help to find ways that satisfy these criteria. Besides, literature is reviewed to prevent reduction in efficiency by investigating storage assignment methods.

5. Literature review

The main purpose of this chapter is to find an answer to some of the knowledge questions. The questions that will be answered are:

- What is a Kardex Remstar Vertical Lift Module and how does it work?
- What alternative FIFO storing methods do there exist for Vertical Lift Modules?
- What possibilities are there in the literature to optimize space utilization in a VLM system while having low travel times?
- What classification methods do there exist to distinguish parts for different purposes?

The answers on questions above can help to reduce the number of superfluous bins and to optimize the operational strategy. To be able to achieve this, a literature review is performed to find answers to the questions above.

5.1 Alternative FIFO storing methods in a VLM

Benchmark is encountering troubles with storing parts in their VLM systems due to lack of space. This first section will provide possibilities to reduce the amount of superfluous space in use while keeping FIFO storing possible and without placing parts in the same location.

To start with a good foundation of this section, the Kardex Remstar VLM will be outlined first. After that, the possibilities for FIFO storage within a VLM system are described.

5.1.1 Kardex Remstar

Kardex Remstar is a producer of dynamic storing systems. These systems can be implemented in warehouses, production plants or distribution centers. Dynamic storing systems automatically store products. The level of automation can be adjusted to preferences customer. Next to that the density and performance can be adjusted to customer's requirements too. All these settings depend on the business processes within a company, and the items that have to be stored.

Next to the storing system, Kardex provides flexible and modular software packages. These software packages can be adjusted to the needs of the customer and integrated into an existing ERP.

The dynamic storing system Benchmark adopted is a Vertical Lift Module (VLM). A VLM is an enclosed system of trays that are vertically arranged and stores products on both sides of the system with an extractor device placed in the center (figure 12). With one push on the button or by scanning a barcode, the system automatically delivers the desired tray with stored items. The modular design of the shuttles provides the possibility to add or remove modules, whenever requirements of the customer change. The VLM can this way provide floor space reduction up to 80%. The system works according to a parts-to-picker principle, meaning that pickers manually store and pick parts.

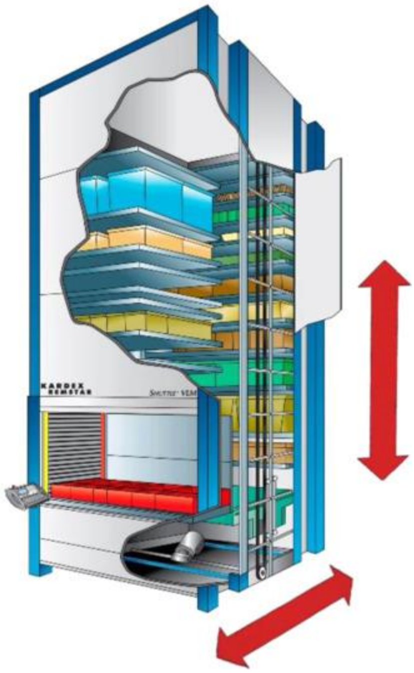


Figure 12: Vertical Lift Module from the inside. Reprinted from "A throughput model for a dual-tray Vertical Lift Module with a human order-picker" by G. Dukic et al., 2015, International Journal of Production Economics, Vol. 170

The worker can request the plateau with bins where the worker has to store or pick parts. In figure 13 is depicted how this looks like. Kardex offers multiple options of interfaces to improve warehousing processes even more. One of these is the barcode scanner that can be used for order confirmation, picking and confirming (Kardex Remstar, 2018).

Figure 13: [Vertical Lift Modules]. Reprinted from Kardex Remstar website. Retrieved from https://www.kardex-remstar.nl/nl/opslag-magazijnbeheer-materiaalbeheer-solutions/verticale-liftsystemen.html

5.1.2 Alternatives to store parts FIFO in VLM systems

A VLM is on itself known to make optimal use of space. This may be a reason that storing parts in a VLM while maintaining FIFO picking and increasing the number of locations offers little possibilities in literature. Maintaining FIFO storing can be performed in two ways. The method by which parts are stored inside the system (currently applied by using separate bins) or the use of adjustable bin sizes. Alternatives for the second approach are studied below.

1) The use of dividers within bins

Storing parts in a Kardex VLM can be organized by putting parts in bins. These bins are typically made of durable plastic and can be reused. As mentioned before in section 3.2, bins are available in specific dimensions. Next to the bins, Kardex Remstar provides dividers to create smaller compartments within a bin. One type of dividers is depicted in figure 14.

Figure 14: [bin dividers]. Reprinted from Kardex Remstar website. Retrieved from https://www.kardex-remstar.nl/nl/opslag-magazijnbeheer-materiaalbeheer-solutions/verticale-liftsystemen.html

Dividers in a bin have several advantages. They help to streamline operations, save space and supply a simple overview. Small parts like screws can easily be divided over one bin which will make utilization of bin use higher. The dividers are particularly effective for holding bulk quantities of very small parts, which can be sorted and handled more easily in dedicated bins. The second advantage is protection of parts. Open storing in the Kardex will increase the chance of exposure to dust and dirt, which may decrease the useful life of a part. The third advantage of the use of dividers is increased accuracy. Many bins offer a spot where labels can be placed to identify contents. These labels on the dividers in the bin make it easier for pickers to know which parts in the bin they have to pick. Furthermore, accuracy and productivity can be increased since only one bin has to be retrieved instead of two when not all parts for one item are stored in the same location (Dube, 2018).

By using dividers, the exact number of locations required can be created. Reconfiguration of dividers can be performed at any time to accommodate changes in the quantity or the size of products. Kardex Remstar states the following about the dividers they supply (Kardex Remstar, 2018):

- Perfect fit for the Kardex Remstar Vertical Lift Module Family
- Flexible in height
- Flexible in bin size layout
- More efficiency
- Easy to configure with the Kardex Remstar software
- Light and robust construction
- Superior filling rate
- Better pick accuracy
- Looks clean and organized

2) Other types of part dividers

Kardex Remstar is not the only one who supplies possibilities to divide parts in a VLM. Another supplier is Flexcontainer, who delivers dividers that can be adjusted to customer needs. In figure 15 and 16 you can see how this alternative looks like. The partitions can be replaced at any time (Flexcontainer, 2018).

Figure 15: [Dividers from Flexcontainer]. Reprinted from Flexcontainer website. Retrieved from http://flexcontainer.com/divider-systems/

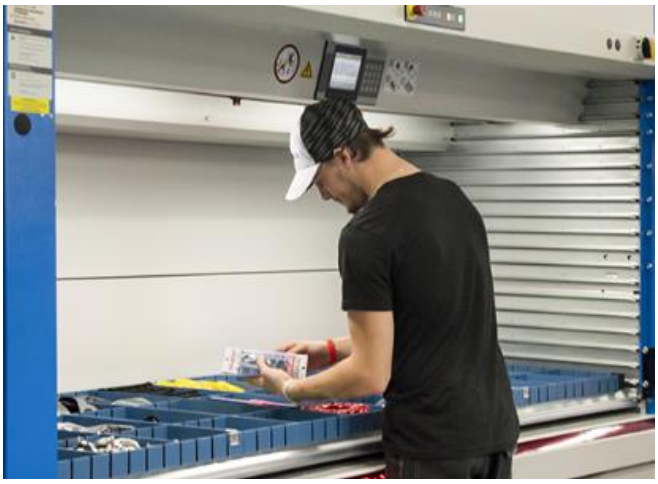


Figure 16: [Picker with dividers from Flexcontainer]. Reprinted from Flexcontainer website. Retrieved from http://flexcontainer.com/divider-systems/

Conclusion of alternatives to store parts FIFO in VLM systems

There exist a few alternatives to apply FIFO within the VLM by using adjustable bin sizes. These alternatives are to use bin dividers or to use a type of adjustable bins. The necessary number of locations can this way be created at any time.

In the following section, storage assignment methods are investigated. Mainly to maintain or even increase the efficiency within the VLM when parts are placed into fewer bins, which are intial possibilities 1 and 2 from section 4.4.

5.2 Storing assignment methods

The method by which parts are currently stored inside the VLM is by assigning bins to a random location in the VLM. Benchmark appears to be very firm in this method to assign stock to a location. The company informally mentioned that the currently applied storage assignment method is sufficient. An example by which this objective was confirmed, was the referral to other theses performed at the company. Meanwhile, the company is dealing with space management problems. These two things together make it seem like a good moment to take the applied storage assignment method into doubt.

In this section, a thesis about the implementation of VLM systems at Benchmark performed a couple of years ago will shortly be discussed first. This thesis already investigated the optimal storage assignment method once. After that, possibilities for optimal storage assignment are investigated with help of literature. This will be done by searching for methods that reduce storing and picking time, while maintaining efficient use of space in an AS/RS in general and in VLM systems in specific. Lastly a conclusion will be based on the information altogether.

Motivation from literature

Several authors wrote about why it is important to investigate the optimal storage assignment method. A few of these reasons are written below:

For a warehouse to be efficient, it should take into account the reduction in traveled distance, in costs, and in amount of space used. This means the required space should be small as possible and the total traveled distance and time should be minimized when searching for the "best" location for stock (Liu, 1999)

In a typical warehouse management system, the order-picking usually costs are around 55% of total warehousing operating costs and exists of around 55% traveling time. Hence, how to reduce the travelling distance when receiving a picking order becomes an important issue (Geng, Li, & Lim, 2005)

Generally, it appears that the distance the AS/RS has to travel to place products in the warehouse, is not influenced by the size of the orders. It is the storage assignment method that influences it (Derickx, 2012)

These reasons show that when the company wants their VLM to work efficiently, it is important to apply a storage assignment method in the VLM that requires little space and requires low travel times.

5.2.1 Thesis about implementation of Kardex at Benchmark

In 2014, A.J. Jansman performed a study about the implementation of Kardex VLM in the warehouse of Benchmark Electronics. This was around the same time the Kardex systems were implemented at the company. To find out how Jansman came to the optimal storage assignment method, the results are presented and discussed. In his investigation, he answered the following question:

How do logistic processes at Benchmark have to be designed to be able to in the future work with the VLM systems and increase efficiency and reliability in the warehouse?

Jansman compared three different methods. The first one was to assign fixed locations to all products, the second to use free locations that are tracked by the Kardex software PowerPick and the third was the use of fixed locations when the Kardex determines an optimal route in the system to make sure the Kardex has to make little movements as possible during the storing process. The last method was implemented at VDL, a company in Almelo that produces comparable products as Benchmark (Jansman, 2014).

Jansman concluded that the second method was the best method for Benchmark, which is also the method that Kardex Remstar recommended. He based his choice on the outcome of the AHP-method (Analytic Hierarchical Process). In this method, he used the following criteria and weights to determine the best option:

Table 4: Criteria and weights from AHP of thesis Jansman

Criteria	Weight
Number of actions	0.06
Probability of human mistakes	0.58
Speed of storing	0.10
Speed of picking	0.14
Flexibility and Use of space	0.12
Consistency ratio[2]	*18.29 (Relatively good)*

The use of free locations seemed to score best on the criteria:

- Reduce probability of errors during picking
- Flexibility and use of space
- Speed of storing

Conclusion of the thesis

Jansman did not take into consideration optional storing assignments from literature, while literature could provide useful information about how to choose the optimal storing assignment method. To find out if the use of free (random) locations is the best storage assignment method, storage assignment methods will be studied in section 5.2.2.

[2] The consistency ratio: The lower this ratio, the better the reliability of the assessment. Below 10, the ratio is "very reliable". Between 10 and 33 the ratio is "reasonably reliable". The score of 18 was seen as sufficient in the investigation of Jansman.

5.2.2 Storage assignment methods

A small number of scholars studied space efficiency within Vertical Lift Modules. This has been confirmed in the literature review of Rosi, Grasic, Dukic, Opetuk, and Lerher (2016). Their review concludes that systems like carrousels and VLM received far less attention than other AS/RS systems. According to Daria, Martina, Alessandro, Manuel and Fabio (2015), the VLM systems fairly differ from other AS/RS systems, though this may not seem the case. Daria et al. states that, if possible, it has to be taken into account that the systems work differently in some ways. Since the amount of available literature about storage assignment is limited, storage assignment methods for AS/RS systems in general are studied first to obtain ideas. This information is taken into account when studying storage assignment methods for VLM in specific.

5.2.2.1 Storage assignment in AS/RS systems

There are many scholars who studied storage assignment methods in AS/RS systems. Most of them studied travel times of the system when applying a particular storage assignment method or by comparing several methods. A review to these articles resulted in five methods that are mostly applied according to Roodbergen and Vis (2009).

Most common storage assignment methods

Roodbergen and Vis performed a survey to available literature on automated storage and retrieval systems from the last 30 years. The survey provides a broad overview of possibilities in AS/RS. Interesting for this thesis are the storage assignment methods the article is writing about. The applicability for each of the mostly applied storage assignment methods is studied in this thesis. The storage assignment methods that are mostly applied according to Roodbergen and Vis are:

1. Dedicated storage assignment
   Assigns each product to a fixed location in the system. Replenishment always occurs at the same location.

2. Random storage assignment
   All empty locations have the same probability of being chosen to store incoming products (almost equal to the closest location assignment method in practice).

3. Closest open location storage assignment
   The first empty location encountered by the system will be used to store the products.

4. Full-turnover-based storage assignment
   The locations products are stored are based on the frequency of demand for the product. Products that have most demand are stored close to the I/O point and slow-moving products are stored further away.

5. Class-based storage assignment
   The class-based storage assignment method divides the warehouse into a number of zones. Within these zones, random storage assignment is applied. The number of zones can be adjusted to requirements of the user.

In table 5, the advantages and disadvantages of each storage assignment method are presented. All information in the table is gathered from literature.

Table 5: Advantages and disadvantages of different storage assignment methods for AS/RS (from literature)[3]

Method	*Advantages*	*Disadvantages*
Dedicated	Heavy products can get fixed locations at the bottom	High space requirements
	Can reduce average cycle time	Low space utilization
Random	Efficient use of space	Travel time not efficient due to randomly chosen storing locations
Closest-location	Locations around I/O point are generally more filled, requiring less travel time of system	Not taking into account travel times
Full-turnover	Products with most demand have most probability to be stored close to the I/O point, reducing travel time of the system	Turn-over frequencies have to be known
		Demand changes, causing locations having to change too to keep efficiency of the method
Class-based	Effective way to reduce travel time	Using more classes results in more space required
	Prevents periodic repositioning of products that is needed in full-turnover based	More space is required compared to random assignment
	Class-based and volume-based provide almost equal savings, but class-based requires less data-processing	
	Significant reduction in travel time of the system compared to random assignment	

Comparing the storage assignment methods

Travel times is according to Hausman, Schwarz, and Graves (1976) and Graves, Hausman, and Schwarz (1977) an appropriate analytical tool to compare assignment policies. Besides, the space utilization in the VLM is an important factor in this thesis, that has to be taken into account when determining the best storage assignment policy. Therefore, the mostly applied storage assignment methods from Roodbergen and Vis are compared based on travel times and space requirements.

[3] References of table 5: Graves, Hausman, & Schwarz (1977); Yang, Miao, Xue, & Ye (2015); Chen, Langevin, & Riopel (2007); Ishigaki & Hibino (2014); Manzini, Gamberi, & Regattieri (2006); Eynan & Rosenblatt (1994); Muralidharan, Linn, & Pandit (1995)

Dedicated

This method is not seen as an optimal method to reduce travel times. Full-turnover and class-based locations are a type of dedicated storage, since the location parts are stored is not chosen fully random. In plain dedicated storage, popularity of parts is not taken into account, causing the travel times to be lower than full-turnover and class-based storage. Besides, requirements for space are high compared to random storage assignment.

Random

Travel times are relatively low and space utilization is relatively high compared to other methods. The choice for the best method to assign products lies at the company itself, but different scholars showed that analytic studies and simulation studies resulted in full-turnover based and class-based storage assignment to outperform random storage in travel time. However, randomized storage requires little storage space compared to other storage assignment methods.

Closest-location

This method has not received a lot of positive attention from scholars. The method is similar to random allocation and does not seem to receive very good results concerning travel times, since popularity of parts is not taken into account when determining the storage location.

Full-turnover based

When turnover rates of products are known, this is a proper method to apply. The products with most demand can be stored close to the I/O point to reduce storing and picking time. Full-turnover based storage is a type of dedicated storage, resulting in a relatively low space utilization. When full-turnover based storage is applied, calculating the optimal locations once every period is best to maintain the method. The choice to apply this method can best be based on the probability demand changes over time.

Class-based

The travel time the system needs to pick products with this method is low compared to other storing methods. The utilization of space depends on the number of classes that are used and the products that are allocated to these classes. It is recommended to use little classes as possible and to take into consideration how often products have to be picked. It is most efficient to locate products staying in the system the shortest close to the I/O point of the system. Since class-based storage implies random allocation inside classes, this method is a good alternative for maintaining both low space utilization from random allocation and low travel times due to locating popular parts on places close to the I/O point.

The article from Hsieh and Tsai (2001) investigates a class-based storage assignment method that classes products based on their BOM. Hsieh and Tsai compare this assignment method to the random allocation of products and obtained that BOM class-based storage assignment is scoring better regarding throughput and travel times.

To prevent periodic repositioning of products, class-based policy can be applied to achieve better throughput compared to full-turnover based.

Conclusion of storage assignment methods in AS/RS

Scholars that studied storage assignment policies in AS/RS systems are most positive about the class-based method when determining the best location for products. Since most scholars focused on travel times, this is not surprising. When products that have to be stored and picked the most are placed close to the I/O point, travel times will be minimized. Full-turnover based storage assignment also minimizes travel times, but turnover rates have to be known and relocation may be necessary due to changing demand.

The number of scholars who studied space utilization of the system is less, causing random allocation of products to be less often mentioned as an optimal storage assignment policy. However, according to multiple scholars, this method appears to score best on utilizing space within the system. Since class-based storage assignment combines dedicated and random allocation of products, it turns out to be a good alternative to optimize space utilization and travel times within the system. An optimal storage assignment strategy within AS/RS-systems is now obtained for the purposes of this study. In the next part it will be established if this strategy is also optimal for VLM systems in specific.

5.2.2.2 Storage assignment in Vertical Lift Modules

In the review to storage assignment in AS/RS systems, the class-based storage assignment method turned out to give the best results in both space utilization and travel times. According to Mantel, Schuur, and Heragu (2007), results from AS/RS and VLM can differ since there is a difference between AS/RS systems in general and VLM in specific. This is due to the fact that an AS/RS systems assumes to have dual command transactions and VLM realizes multiple command transactions. In other words, retrieval actions for one order occur all at once. The literate review to Vertical Lift Modules below studies if the results from AS/RS are the same for VLM in specific and if there exist other alternatives that give even better results.

Optimizing warehousing processes in Vertical Lift Modules

The article of Rosi et al. (2016) studied performance of single tray VLM compared to other automated warehouse systems in terms of reducing the mean cycle time of transactions. The simulation in their investigation compares different models where the height of the VLM and the velocity of the lift itself were changed. All models perform random allocation of products. The article concludes the height of the VLM and the speed by which the system can move to influence the travel time of the system significantly.

Daria et al. (2015) studied storage assignment methods in VLM systems. They state that small parts require a high amount of space within the system when storing them in a big location, while the space that is really needed could be reduced. A solution could be to create a separate area for small objects. The main benefit of this is the reduced total needed space and besides that, the travelled distance of the system.

Mantel, Schuur, and Heragu (2007) came up with a new storage assignment method called Order Oriented Slotting (OOS) method. This method assigns products in a VLM in such a way that the total travelling time of all tours is minimized. OOS does what the name tells, it assigns products to a location based on the order products are meant for. The method therefore takes into account multiple command transactions from the VLM, which other methods like the Cube per Ordex Index (COI)[4] do not. The results of the study of Mantel et al. show that the total time of picking all orders is minimized with this OOS (see figure 17).

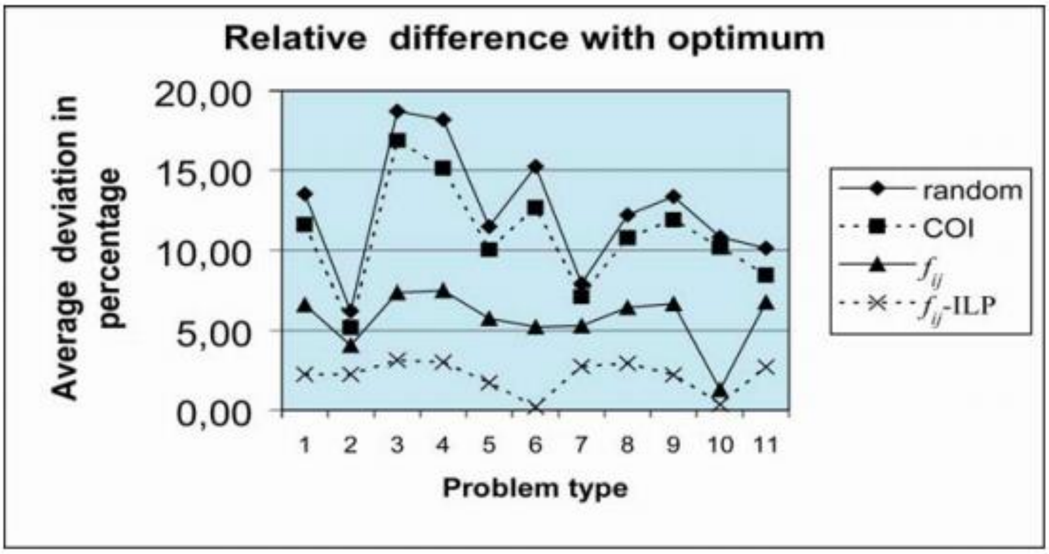


Figure 17: Relative difference with the optimal values for the various problem types. Reprinted from "Order oriented slotting: a new assignment strategy for warehouses," by R. Mantel, P.C. Schuur, and S.S. Heragu, 2007, *European Journal of Industrial Engineering, Vol. 1, Issue 3/2007*, p.301-316

Nicolas, Yannick, and Ramzi (2017) studied a type of class-based storage. In this study, classes are based on the order for which products are meant, comparable to Mantel et al. The study of Nicolas et al. found that most companies who adopted a VLM in their company, apply basic tools for batching products. One of these basic tools is the "first come first served" strategy that can be compared with FIFO. These basic tools are generally far from optimal. The objective of this study was to create batches in the VLM, which has been proven to be a critical operation for order picking efficiency. The total time needed to pick all orders was hereby minimized. This time only depends on waiting time of the picker to retrieve plateaus and picking time for all order lines.

Furthermore, Nicolas et al. mentions that one of the main objective of warehouse managers is currently to achieve higher throughput of the VLM system. The throughput seemed highly correlated to the batching decision and therefore plays an important role. Time and cost savings could be reached when products from several orders have to be retrieved from the same tray. In this case, it is efficient to retrieve them together instead of requesting the tray multiple times.

[4] COI will be explained in section 5.3

Many companies adopted the strategy to batch products according to their arrival or due date until the batch is full, which did not appear to be an optimal method. A more optimal model to minimize total completion time seemed equivalent to minimizing the sum of the number of trays visited by the VLM for each batch. This model was applied in two real companies. Results showed savings in completion time of 32% and 26% respectively. Some findings were mentioned in the end of the article of Nicolas et al. Two of these are that the model works better when the number of orders increases and that an increase in the number of order lines per model results in deterioration of performance.

Conclusion of storage assignment methods in VLM

The main goal of this review to storage assignment methods was to find a way to have low travel times in a VLM while maintaining space efficiency. According to the available literature about storage assignment in Vertical Lift Modules, not many companies apply an optimal method to locate their products.

Many scholars that studied travel times in VLM, performed research to storage assignment methods with separate areas for different classes. Storing parts within classes in the system turned out to be an optimal way to reduce travel time of both AS/RS systems in general and VLM in specific, when an appropriate number of classes is used. Besides, the random allocation within the classes maintains space efficiency in both systems.

The optimal choice of classes is studied more actively by scholars who studied storage assignment methods in VLM. Since the VLM system is able to retrieve parts from multiple locations at once, the picking process fairly differs from AS/RS systems. When deciding which classes to apply and where to locate them in the VLM, it is recommended to take into consideration the height of demand and/or the importance of classes. Parts with high demand or importance are preferably located close to the I/O point to be able to keep travel times low. Furthermore, it is recommended to take into account multiple command in a VLM when making a decision about the optimal storage assignment method. Meaning that when deciding about classes, it is recommended to locate parts that have to be picked at the same moment close together or preferably on the same plateau.

Class-based storage assignment with random allocation within classes showed the best results concerning both optimizing space utilization and low travel times of the system. Subsequently, it is wise to investigate appropriate classes for Benchmark. Classification methods are studied in section 5.3. In chapter 6, the best classification method for the company is determined with help of the AHP.

5.2.2.3 Comparing storage assignment method to previous thesis

The thesis from Jansman compared three storage assignment methods. Two of them make use of free locations and one uses fixed locations for parts. The method with free locations where the VLM determines an optimal route for the system turned out to score best in the AHP. Unfortunately, Jansman did not take into account many storage assignment options.

A literature review showed that there exist more assignment methods that could be applied in a VLM than Jansman offers. These methods are discussed in section 5.2.2.1 and 5.2.2.2. The class-based storage assignment method with random allocation within classes turned out to be the best alternative to achieve low picking time and high space utilization. When comparing this alternative to the results from the thesis of Jansman, the class-based storage assignment method is assumed to score better on every criteria. No new calculation of AHP is required to imply that the class-based storage assignment method with random allocation scores best in the AHP. To be able to prove this method to outperform the current storage method, the method has to be simulated or implemented.

5.2.3 Storage alternatives in VLM systems

The results from the performed literature reviews in this chapter resulted in better specified storage alternatives that can reduce the number of superfluous bins. These alternatives are presented below.

Alternatives to store parts FIFO in VLM systems

1) Reducing the number of bins by placing identical parts in fewer bins, with FIFO picking based on MBA-number
2) Reducing the number of bins by placing different parts in fewer bins, with FIFO picking based on MBA-number
3) Alternative FIFO storing methods for in Kardex ZKDX1001
    a. Bin dividers inside bins
    b. Adjustable partitions

Initial possibilities 1 and 2 place parts with different MBA-numbers within the same bin. In the literature there are no articles available about this specific subject. To maintain efficiency in the VLM, which is an important subject according to the warehouse manager, alternatives 1 and 2 are recommended to be implemented with class-based storage assignment.

Literature research to option 3 found two alternatives in the case of maintaining FIFO while being able to adjust the number of locations in the VLM. These alternatives are the use of bin dividers and the use of adjustable partitions.

5.3 Classification methods

In section 5.2, the class-based storage assignment method with random allocation inside classes appeared to be the optimal method for the VLM systems of Benchmark. This method requires classification of parts to function appropriately. There is a lot of literature available about the classification of products. The most studied and successful ones are briefly described below.

Motivation from literature

According to Huiskonen (2001, cited in Do Rego) and Boylan, Syntetos and Karakostas (2008, cited in Do Rego), classification of products is essential in inventory management. Besides that, the increasing complexity of products and their life cycles generates an increasing amount of active codes and risk of obsolescence. However, most companies only use classification to be able to forecast demand. They do not use it in inventory control, which could be very helpful (Do Rego, de Mesquita, 2011).

ABC

The ABC-classification is used a lot in practice. In this method, products are divided in three classes, class A, B and C as the name tells. Class A consists of relatively few items in inventory, but together encompass a relatively large annual use value. Class C contains a relatively large number of items, but encompasses a relatively small annual use value. Between classes A and C is class B, containing all items that are left. Some studies claim that class B could be excluded (Ramanathan, 2006). Companies employ this ABC classification method to have an efficient control of inventory on a large number of items. The only criteria this classification has is the annual dollar usage (Torabi, Hatefi, & Saleck Pay, 2012). A drawback according to many articles studying the applicability of the ABC classification, is the lack of criteria.

Multi criteria ABC

The task of the decision maker is to determine the priority for every item in inventory. By this, a sensible classification can be reached. The classification method that many industrial companies adopted is the ABC classification. Since this classification method is based on only one criteria, the annual usage costs, the method is often not sufficient enough. If this criteria is the only criteria were classification is based on, some crucial qualitative criteria such as obsolescence of an item are ignored. To overcome these limitations, researchers searched for ways to incorporate criteria's in the ABC classification. Analytic Hierarchy Process (AHP) is one of these techniques, that is proposed by many researchers (Cakir & Canbolat, 2008). This technique is a multiple criteria decision-making tool that can be used in almost every decision making process (Vaidya & Kumar, 2006).

Cube per Order Index

The Cube per Order Index is a method that aims to enhance order picking efficiency. The model can be used to rank items. According to this ranking, items are assigned to locations that minimize picking costs and optimize storage space. The location an item is assigned to, is based on how frequently an order is picked. (Caron, Marchet, & Perego, 2010).

Life-cycle based

Do Rego & de Mesquita (2011) in their literature review write about management of spare parts. Spare parts for industrial maintenance are recommended to be classified based on their life-cycle state. For example the VED-method, where V stands for Vital, E for Essential and D for Desirable (Gajpal, Ganesh, & Rajendran, 1994).

With current existing software, items can be classified dynamically. This way inventory control can be enhanced. In table 6, a recommended option for classification of parts based on their life-cycle state is given (Do Rego, de Mesquita, 2011). Items that have demand and are still used in production are recommended to be classified according to Pareto's ABC values.

Table 6: Classification of parts based on life cycle

Class	Life cycle phase
New	Parts in production for less than 6 months
Active	Parts in production for more than 6 months
Orphan	Parts in production only for replacement
Terminal	Parts out of production with remaining inventory
Inactive	Parts out of production without inventory

Order-oriented slotting

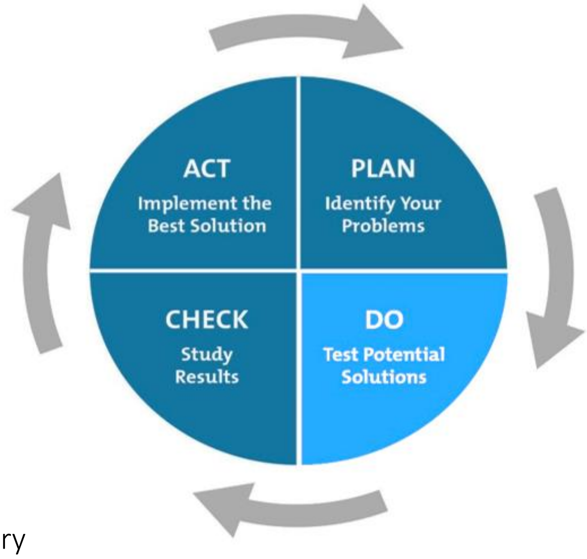
Mantel, Schuur, and Heragu (2007) came up with a new strategy for assigning Stock Keeping Units (SKUs) to a storage location. This strategy is called Order Oriented Slotting (OOS), which was especially tested in a VLM system. The OOS strategy was devised to minimize the total time to pick all orders. The set of orders and a routing policy is needed to let heuristics determine the optimal routing policy. The method may let you think of the COI that was outlined before. The difference with this strategy is that in OOS, next to the frequency of picking, the appearance of products in orders is also taken into account. This is in the case of multiple command transactions within a VLM an improvement, since it can decrease travel times even more (Mantel, Schuur, & Heragu, 2007).

Conclusion of classification methods

Literature tells that classification of parts is important to improve inventory management, especially when complexity of products is increasing or the developing of the life-cycle causes problems. For Benchmark, it is useful to classify parts when the class-based storage assignment method is implemented. When classification is applied appropriately, it can reduce the amount of work, costs and/or space, and increase efficiency within the VLM. In section 6.4, the optimal classification strategy to decrease travel times and maintain efficiency in space utilization is determined.

Conclusion

Two alternative FIFO storing methods for Kardex ZKDX1000 are to use bin dividers or to implement adjustable bins. Two other ways to reduce the number of superfluous bins are placing parts in fewer bins. The storage assignment method that appeared to have the best effect on space utilization and travel time in a VLM is the class-based storage assignment method with random allocation. Five classification methods were presented for these classes. The best method to achieve efficiency in space and travel times is determined in chapter 6.



6. Do: Implementing improvement

The Do of the PDCA-cycle allows the improvement from the Plan to be performed in reality. All options from section 4.4 (see 6.1) to reduce the number of superfluous bins could achieve the goal of this research. In this chapter, the results of the preferred solution are outlined and a sufficient classification method is chosen, with help of the AHP.

Benchmark wants to make improvements based on the theory Kaizen. One of the core principles of Kaizen is involving employees during improvement and monitoring. The motivation of employees should definitely be taken into account, since the employees are responsible for improving and maintaining performance levels (Berger, 1997). To make sure employees are involved in the decision making process, their opinion about the obtained improvement possibilities is discovered in this chapter.

6.1 Preferences of the company

To take into account the preferences of the company, all options have been proposed to five warehouse employees, the warehouse manager, and two supply chain analysts. They were able to explain their choices in the questionnaire.

The following options were provided in the proposal:

1. Refilling bins in the VLM with identical parts in the storing stage
2. Relocating parts from multiple bins to fewer bins, once in a couple of weeks
3. Refilling bins in the VLM with different parts in the storing stage
4. Inserting adjustable bin sizes, with or without use of dividers

Table 7: Preferences of warehouse employees and manager

Warehouse	Employee 1	Employee 2	Employee 3	Employee 4	Employee 5	Manager	Weighted score
Refilling bins with identical parts	4	2	2	1	2	2	*2,17*
Relocating identical parts to fewer bins	3	2	3	3	3	2	*2,17*
Refilling bins with different parts	1	2	1	1	1	1	*1,17*
Adjustable bin sizes	5	4	1	1	2	1	*2,33*

Table 8: Preferences supply chain analyzers and score in total

Operations	Analyzer 1	Analyzer 2	Weighted score	Total weighted score
Refilling bins with identical parts	4	5	*4,5*	*2,75*
Relocating identical parts to fewer bins	5	4	*4,5*	*3,125*
Refilling bins with different parts	1	3	*2*	*1,375*
Adjustable bin sizes	3	4	*3,5*	*2,625*

The results in table 7 and 8 show that relocating identical parts is the preferred way to reduce the number of superfluous bins according to employees of the company.

Further findings of the questionnaire

- The scores supply chain analysts (operations) gave were more optimistic than the scores of warehouse employees and the warehouse manager
- Operations considered the first option as an interesting option, while the warehouse employees were less enthusiastic
- Bin dividers were implemented at a previous company where one of the two supply chain analyzer worked one year ago. In that company, the solution was considered as successfully implemented
- The option to put different parts within fewer bins gained relatively low scores from all employees

6.2 Results of reduction

Due to preferences of the company, the number of superfluous bins can best be reduced by placing identical parts in fewer bins. This can be approached by option 1 and 2 (section 6.1):

1. Refilling bins in the VLM with identical parts in the storing stage
2. Relocating parts from multiple bins to fewer bins, once in a couple of weeks

Both are presented as approach to solve the problem, since the location parts will be stored is the same. Only the performance of the storing process differs. This means the results for both approaches is initially the same.

Benchmark deliberated they require a maximum of two bins per part. In this case, a release of 879 bins is possible for both options 1 and 2. This results in a reduction of (879/9761) = 9%. The calculation is just an approximation, because it is not certain if the total number of parts for one type fits in two bins. Exact dimensions of parts are necessary to calculate the real reduction. A way to determine this is provided in chapter 7.

6.3 Results of reducing only a selection of bins

For multiple reasons, the company could prefer to reduce the number of superfluous bins only for a selection of parts. A good possibility to distinguish parts is to take their necessity into account, based on the lifecycle (Do Rego & de Mesquita). Presenting an alternative category of parts provides Benchmark the opportunity to choose which bins they want to tackle. In the case of tackling only a selection of bins, the goal of reducing the superfluous space in use from 9 to 0% cannot be reached.

Due to the statement above, the two presented categories are:

1) All parts in superfluous bins
2) Obsolete parts in superfluous bins

1) All parts in superfluous bins

The total bin reduction for superfluous bins could be 879, which has already been established in chapter 1. When the company wants to change the maximum number of bins per part, the additional bin reduction can be calculated with help of the calculation presented in section 1.3.2. A more reliable way to determine the possible reduction is presented in chapter 7.

2) Obsolete parts in superfluous bins

There are two types of classifications Benchmark uses to classify abundant parts. These classifications are known as excess[5] and obsolete[6]. To indicate the state of parts, Benchmark uses signal codes. Signal codes are explained in section 6.4.

Table 9 shows the number of abundant, superfluous bins. Code "All" is given when parts have no demand and are stored in the VLM for more than 180 days. The code "Obs" is given when parts are stored for longer than 180 days and currently classified as obsolete in Baan. The code "Eol" is given when parts are currently classified as excess in Baan.

[5] Excess: A product is excess when there is more inventory of a product than within six months will be used

[6] Obsolete: A product is obsolete when there is no demand for the product within six months

Next to bin reduction to a maximum of two bins per part (column 4), bin reduction to one bin per part is presented in the third column. This is because obsolete parts move slowly, which may make the company prefer to store identical, obsolete parts altogether when possible. The total bin reduction for superfluous, obsolete bins according to the definition of obsolete could be 88 when parts are placed in maximum one bin. This is (88/9761 = 0,01) 1% of total.

Table 9: Reduction of abundant, unnecessary bins

Code	Customer	*Bins to reduce (1)*	*Bins to reduce (2)*
All	All	88	16
All	ASML	48	10
All	THL	25	2
All	Other	15	14
Obs	All	4	1
Obs	ASML	3	1
Obs	THL	1	0
Obs	Other	0	0
Eol	All	3	1
Eol	ASML	0	0
Eol	THL	3	1
Eol	Other	0	0

One drawback of the approach to classify obsolete bins with codes is that every All and Eol code should in reality be Obs, according to the definition of obsolete[6]. The reason this is not the case is that parts have to be approved as obsolete before this code is assigned. In table 9 can be seen that many parts are not approved to be obsolete. Approving of obsolesce takes time, due to the number of people who have to approve the classification of obsolete. The difference between actual obsolesce and coded obsolesce is quiet big, causing the real impact of tackling only bins with obsolete parts to be hard to establish.

Overview of possible bin reduction

Based on the results above, the following overview can be made:

Bin reduction for all parts in superfluous bins	879
Bin reduction for obsolete parts in superfluous bins	88
Bin reduction for obsolete parts in superfluous bins (approved by code)	4

Remarks

Only (re)locating obsolete parts in fewer bins results in around 1% bin reduction of the total of bins in Kardex ZKDX1001. Since this does not provide in the desired results, further investigation to obsolete bins can be found in appendix 10.5. Here, the number of bins containing obsoletes is studied (not taking in consideration the number of bins for one part).

6.4 Optimal classification method for class-based storage assignment

When Benchmark choses to apply the class-based storage assignment method, this section is helpful to determine the appropriate classification method. When this method is applied well, it should provide an optimal space utilization and low travel times within the VLM.

Currently applied classification methods

Benchmark currently applies four different classification methods, all with different purposes. They use ABC values for counting inventory, item group codes for automatically changing settings in Baan, value class codes for determining order quantities and order intervals and signal codes to indicate the state of parts.

ABC values

ABC values are used to count inventory manually. Parts are categorized based on their value, in category A, B or C. A is returning about 80% of total value, B returns around 15% of value, and C returns around 5% of value. The number of parts in class A is mostly low, while the number of parts in class C is high. The categories are used to determine how often parts have to be counted. The ABC categories can be found in Baan.

Item group codes

Item group codes are used to indicate the product group of parts. In appendix 10.2, all item groups codes are given in a table. The item group is assigned to parts in Agile, a system that manages information of parts. This information is automatically updated in Baan every day.

Value class codes

Value class codes are used to determine the optimal order quantity and date of parts. Baan indicates when operational buyers have to buy parts and how many. This indication is based on the assigned value class codes. It is up to the buyers if they do exactly what the systems tells them or if they try to optimize the purchasing process. The current value class codes are A1, B1, C1, D1, E1, NC, NP, X1, Y1 and S1. In appendix 10.2 can be found what these value class codes imply.

Signal codes

Signal codes indicate the state of parts. The signal codes the company is currently applying are explained in appendix 10.2. Here can be seen that abbreviations are used to describe the state of a part. According to the information in section 6.3, the signal codes that are most important in this project are OBS and EOL, since they indicate obsolesce of parts.

Choosing the best classification method

The possibilities to classify products were discussed above and in the literature review (5.3). The choice of the best method can differ for different purposes. The Analytic Hierarchical Process (AHP) is applied to make the best choice in the case of Benchmark. The AHP weighs options to criteria that are considered as important for making the decision.

This project is trying to reduce the number of superfluous bins in the VLM, while maintaining optimal space utilization and travel times in the warehouse. These factors are kept in mind while determining the criteria for the AHP[7]. The outcome of the AHP is based on how each classification method scores on the criteria in the first row of table 10. The total score of a method is determined by the cumulative score of that option. The weight of each criteria is given in the second row. In this AHP, scores are based on information from the literature review and on discussion with employees from the operations department.

Table 10: Scores of options based on AHP

	Enables efficient use of space	**Enables reduction of travel time**	**Easy to implement**	**Easy to understand**	**Successful in literature**	
Weight	5	4	3	2	4	
COI	5	4	3	3	3	
ABC	3	2	5	4	2	
MC ABC	5	5	4	3	4	
Life-cycle based	4	3	3	3	3	
OOS	5	5	3	3	4	
Item group code	2	2	2	2	1	
Value class code	2	3	3	2	1	
Signal code	3	3	3	3	1	
Score						*Total*
COI	25	16	9	6	12	68
ABC	15	8	15	8	8	54
MC ABC	25	20	12	6	16	79
Life-cycle based	20	12	9	6	12	59
OOS	25	20	9	6	16	76
Item group code	10	8	6	4	4	32
Value class code	10	12	9	4	4	39
Signal code	15	12	9	6	4	46

The MC ABC is scoring best in the AHP with a score of 79.

Conclusion

This chapter found that reducing the number of superfluous bins by placing identical parts within fewer bins in the storing stage or by relocating them to fewer bins once in a couple of weeks is preferred by the employees of Benchmark. Results of both approaches are the same. Chapter 7 provides a possibility to calculate a more reliable impression of the results. Since the company could have multiple reasons for preferring to reduce bins for a selection of parts only, the option to tackle only obsolete parts is proposed. Last, the MC ABC scored best as classification method for Benchmark, according to the AHP that was performed.

[7] The score of options on the enabling of efficient use of space and the reduction of travel time is based on the location parts are stored and the number of classes in use when applying a method.

7. Plan for implementation

An important step to make the improvement successful is by developing a plan for implementation. Two implementation plans are elaborated in this chapter. These are locating parts within filled bins in the storing stage and relocating parts to fewer bins afterwards. The two possibilities could be put into practice with help of different approaches. Three approaches are provided in this thesis. These approaches are established in deliberation with operations and will be outlined in section 7.3. By providing two ways to place identical parts into fewer bins, the company has freedom in choosing their best option.

Two implementation possibilities are outlined in section 7.1 and 7.2:

1. Refilling bins in the VLM with identical parts, in the storing stage
2. Relocating parts from multiple bins to fewer bins, once in a couple of weeks

Both possibilities can be applied with help of the following approaches:

a. Let Baan calculate the amount of free space within a bin
b. Export from inventory in the VLM
c. Physical checking inventory in the VLM

7.1 Storing parts in bins already occupied in the VLM

The first possibility is to batch new parts to a bin that is already occupied and located in the VLM. New parts will be placed together with older parts in one bin when the bin with older parts has free space available. This possibility to reduce bins is recommended to only be approached by option a. The other two options decreases efficiency of warehousing processes significantly, since an export cannot tell how many parts fit inside an existing bin exactly and physical checking of the content of bins takes a lot of unnecessary time.

The performance of this possibility differs somewhat from the current receiving and storing process. Therefore, a process flowchart of implementation possibility 1 is depicted in figure 18. A clearer overview of the change in warehouse processes is hereby presented.

7.1.1 Warehousing processes

1) Receiving

The receiving process changes minimally relative to the existing receiving process. All tasks that are described in the current receiving process (chapter 3) still have to be performed. The only difference is the way by which batching of parts to a location is performed. The batching process changes if there already is a bin stored in the VLM containing the same parts as received. Besides, this bin has to have enough free space available to store more parts. If this is the case, the parts have to be batched to the occupied location in the VLM instead of a location with an empty bin.

When the occupied bin does not have enough free space to store all received parts, the new parts should be divided over two locations. The old bin has to be filled first, before the remaining parts are placed in a new bin. This is necessary to maintain an efficient FIFO picking process. When parts would not be divided over two locations, it may occur that parts with different MBA-numbers are randomly spread over many bins, which increases the chance a picker has to pick the oldest MBA-number from multiple bins.

To be able to a discover the number of parts that has to be located in an occupied bin in the VLM, the parts and corresponding locations should be searched in Baan. How this can be determined will be explained in section 7.3, approach a.

2) Storing

The storing procedure changes under certain circumstances. Currently, new parts generally fit inside one bin and the bin that has to be stored is swapped with an empty bin from the VLM. In the new storing method, the chance that not all parts fit inside one bin during storing is higher. The chance that parts have to be divided over two bins is higher, because the occupied bin is already containing some parts. Dividing the new parts over two bins increases workload a little. Workload increases because parts have to be divided over an old bin and a new "transfer" bin. Storing in this case requires the request of two locations (plateaus) instead of one when applying random storage assignment. The bin that is already occupied will first be filled to the indicated number in PowerPick. The remaining parts stay in the transfer bin and are swapped with a free bin in the VLM. The released bin is transported to the docking department after storing. When all parts fit inside the bin that is already located in the VLM, the transfer bin will be transported to the docking department.

3) Picking

The picking process does not change. It does increase in efficiency, due to the raised chance of parts being divided over less bins. The only difficulty in picking is the recognition of parts. A way to recognize the MBA-numbers of parts has to be implemented.

7.1.2 FIFO recognition

In chapter 4 it was established that FIFO recognition based on MBA-number has to be possible at all time. One way to recognize the MBA-number of parts during picking is by labeling every separate part inside a bin. Parts are most of the time stored in cardboard boxes or plastic bags. When all these boxes and plastic bags are labeled, the picker is able to recognize the parts according to the MBA-number on this label. An easy way to recognize the right MBA-numbers from a label is by scanning the label of the parts. Scanning the label lets PowerPick know which parts have been picked. When the wrong parts are picked, the software shows that these parts cannot be picked since parts with a lower MBA-number have to be picked first.

There exist alternatives to recognize the MBA-number of parts that are not treated in this study. Labelling all parts is most likely in this case, since bins already receive a label to recognize the parts.

7.1.3 Conclusion of the plan

Taking all three warehousing processes together, this method for storing parts in the VLM will probably increase total workload in the warehouse a little. The workload that increases during the storing of parts will more or less be undone by the decrease of workload at the picking process. This is not proven, but assumed. The batching process may take some more time when Baan needs to be checked, resulting in a small increase of total workload. To say something reliable about the amount of workload, the new storing method will have to be simulated or implemented. Based on the simulation or implementation, the Check step of the PDCA-cycle can discover the amount of workload.

Remarks

- One *requirement* for this implementation plan is entering the dimensions of all parts and all bins in Baan. The dimensions of bins have to be entered only once, since the same size of bins are always stored at a certain plateau in the VLM. The dimensions of existing parts have to be entered once and the dimensions of new parts have to be entered when they first come in.
- An *advantage* of this option is that the content of bins can be found in Baan and supply chain analyzers can keep track of the contents. At the moment, the content of bins can only be tracked with PowerPick. This software is only used at docking and in the warehouse.

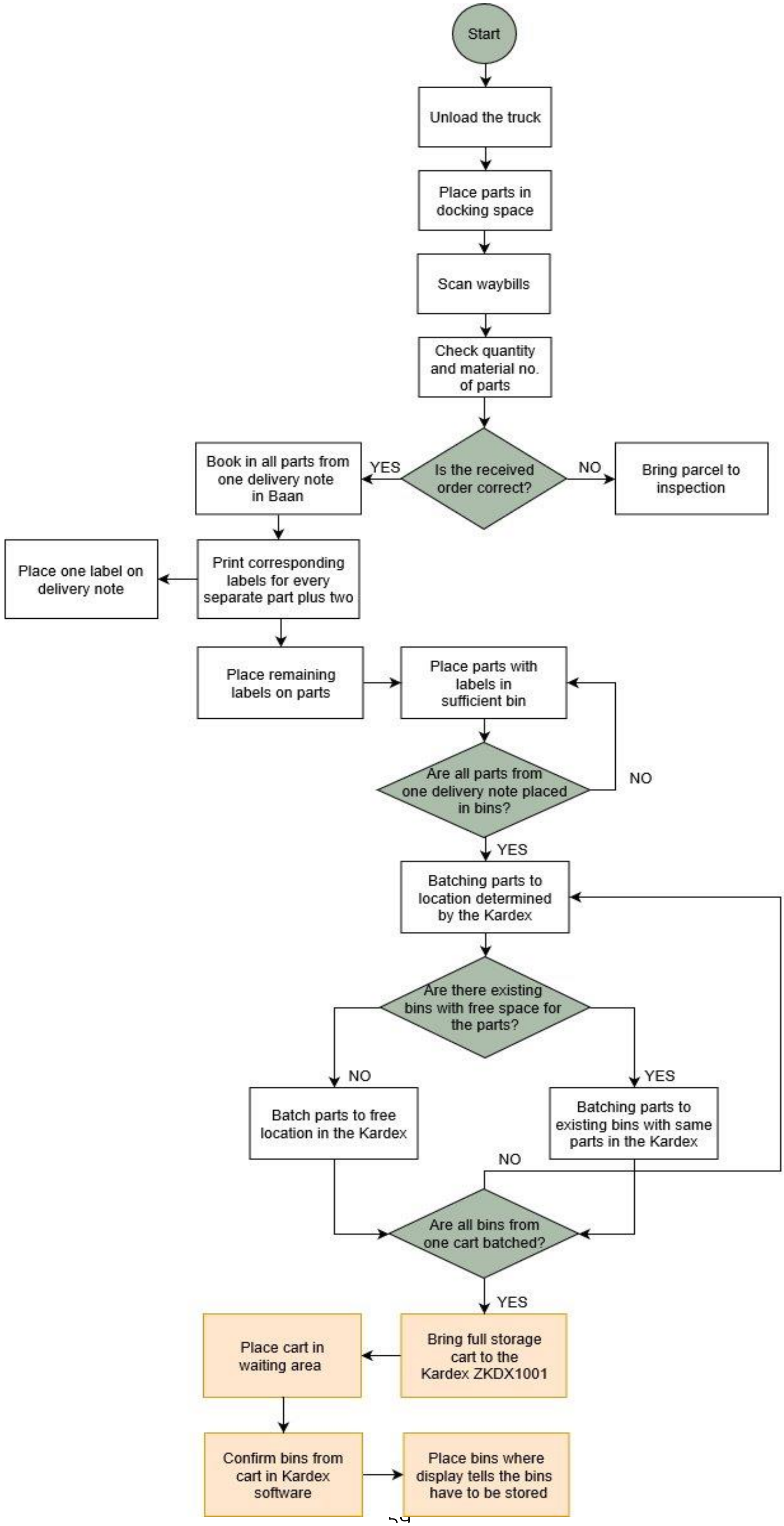


Figure 18: New receiving and storing process

7.2 Relocating parts

Relocating parts is the second possibility to reduce the number of unnecessary bins in Kardex ZKDX1001. The first step in this possibility is to find occupied bins with free space. The second step is to find bins with corresponding parts, that could be divided over the bins with free space. And the last step is to divide the parts over less (in this case two) bins. If the company wants to see results by applying this possibility, it is necessary to make sure one or more bins are released when relocating parts of a certain bin.

The first two steps can be performed with help of approaches a, b and c that were mentioned in the beginning of this chapter. These three approaches are: Letting Baan calculate the number of parts that can be stored within the occupied bins, using an export from Kardex ZKDX1001 and determine the bins that could be released, or performing a physical check of inventory. All three approaches are outlined after explaining this implementation plan.

7.2.1 Warehousing process

Just before the end of this thesis, a new procedure was made about relocating parts from a certain bin size to a smaller bin size. This solution was created to decrease the space in use in Kardex ZKDX1001. In this solution, parts are relocated to smaller, free bins in the VLM.

In the new relocation plan, parts are transferred to an occupied bin. Nevertheless, the procedure for transferring parts from one bin to a smaller one is similar to the procedure in this case. The only difference is that the employee performing the relocation procedure has to search for occupied bins from the same part number instead of searching for free bins. The procedure to relocate parts from big to smaller bins is enclosed in the work instruction called: "Items overpakken van grote naar kleine bak (Kardex)".

7.2.2 FIFO recognition

Recognizing MBA-numbers is, just like implementation plan 1, important in this plan. Performing MBA-number recognition can be the same as in the first plan, by labelling every separate part in a bin. Another possibility to perform FIFO storing is by placing the oldest parts on the left side and the newest parts on the right side of the bin. Differentiation has to be obvious in this case.

7.2.3 Conclusion of the plan

The relocating process takes time from the warehouse employees that did not have to be spend initially. Results of relocating on the other hand are noticeable. The warehouse employees complained about the amount of space that is available in the VLM systems. Spending time to perform the new relocation procedure, causes the warehouse employees to reward themselves by increasing the amount of available storing space.

Remarks

This plan can be performed whenever Benchmark wants (e.g.: once every month). This could be on moments the VLM system is idle and workload for the workers is low.

7.3 Search for bins with free space

The implementation plans for (re)locating parts in fewer bins have been described in section 7.1 and 7.2. Three approaches to search for occupied bins with free space are provided here.

a. Baan shows the number of parts bins can store

Baan has the option to calculate the number of parts that fits into bins. For Baan to be able to determine this number, the dimensions of parts and the dimensions of locations have to be entered in the software.

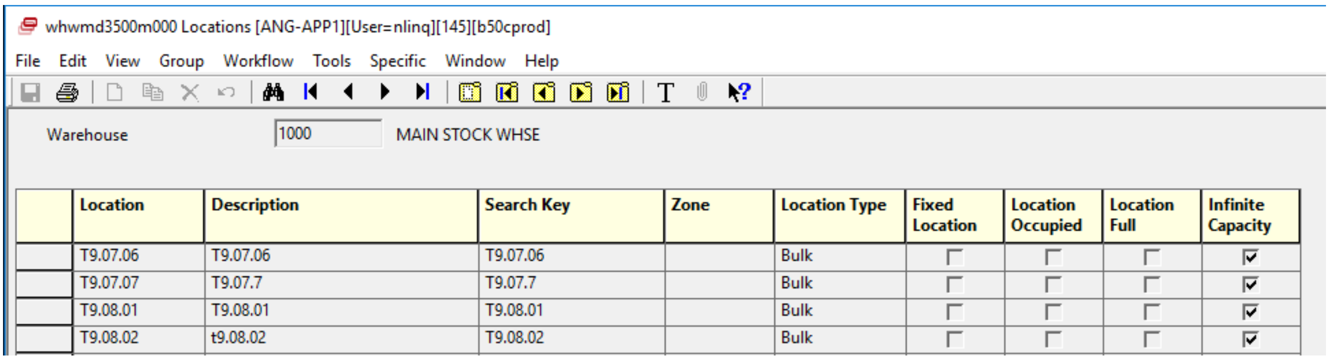
- Dimensions of parts have to be entered with the information of items
  In appendix 10.3 an explanation of how to enter dimensions into Baan is provided

- Dimensions of locations have to be entered into Baan
  Before dimensions of location can be entered, new locations have to be created. How to perform this can be found in appendix 10.4

Kardex ZKDX1001 currently assigns one bin size to a certain plateau. This policy is beneficial in this case, since every location in Baan then always has the same dimensions. Hence, dimensions of locations have to be entered into Baan only once to know dimensions of every location in Kardex ZKDX1001 at all time.

To see if a certain location is occupied and/or full, Baan indicates “location occupied” and/or “location full” with checkmarks as can be seen in figure 18. Currently, only the box “infinite capacity” has a checkmark assigned, because the company does not use the option to calculate content of locations. If Benchmark applies this option to determine the bins with free space, the infinite capacity boxes would be unticked and the “location occupied” and/or “location full” would be checked. This information indicates which bins could be filled with more parts.

The company is not using the option “fixed location”, which is also not recommended. If they did, the random storage assignment disappears and space utilization would decrease.


whwmd3500m000 Locations [ANG-APP1][User=nlinq][145][b50cprod]

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Warehouse 1000 MAIN STOCK WHSE

	Location	Description	Search Key	Zone	Location Type	Fixed Location	Location Occupied	Location Full	Infinite Capacity
	T9.07.06	T9.07.06	T9.07.06		Bulk	☐	☐	☐	☑
	T9.07.07	T9.07.7	T9.07.7		Bulk	☐	☐	☐	☑
	T9.08.01	T9.08.01	T9.08.01		Bulk	☐	☐	☐	☑
	T9.08.02	t9.08.02	T9.08.02		Bulk	☐	☐	☐	☑

Figure 18: Locations in Baan

b. Export from inventory in the VLM

Another way to find out which bins occupy more than two locations is with help of an export from PowerPick. This export returns information from every location in Kardex ZKDX1001. It can be converted to Excel and will then look as follows:

	A	B	C	D	E	F	G	H	I
1	Location	Material	Information 1	Actual quantity	Bin	Date of storing	Processing unit	MBA no.	Count date
2	SH02-035-02-02	4022 103 00738	DRIVER 8X DARLN ULN2803AN	2	B005	20-11-2017 08:55	B005-0124	MBA246431	30-11-2017 07:55
3	SH06-047-06-01	4022 105 00127	HEADER 2X8P-M STR 90131-0768	5	B001	11-4-2018 16:45	B001-3390	MBA221558	
4	SH05-001-19-01	4022 105 00168	JUMPER 2P 68786-202 FCI	18	B001	17-11-2017 12:25	B001-0205	MBA246316	
5	SH03-040-05-01	4022 105 00316	SOCKET DIL 18P PRECIDIP	25	B006	20-11-2017 08:59	B006-0212	MBA246433	21-3-2018 07:42
6	SH02-007-03-04	4022 110 00281	STICKER 25.4X12.7 THT-5-428-10	10000	B002	2-6-2017 07:43	B002-0798	MBA220126	11-6-2018 07:24
7	SH01-010-03-02	4022 496 62921	ESD WARNING LABEL NL/ENG	4000	B002	13-3-2018 08:09	B002-0105	MBA260714	
8	SH06-026-05-02	AIB4022_109_00023	BAG PE 350X550X0.05MM	500	B004	16-11-2017 17:39	B004-0721	MBA00001	20-2-2018 08:10
9	SH03-029-03-01	AIB4022_109_00081	PE BAG 76X127MM	4400	B004	20-4-2018 10:54	B004-0043	MBA265983	26-6-2018 07:28
10	SH06-024-05-02	AIB4022_109_00091	PE BAG 127X203MM	2400	B004	16-11-2017 15:53	B004-0448	MBA246187	
11	SH06-014-09-02	AIB4022_109_00101	BAG PE 205X305MM	1000	B003	17-5-2018 19:38	B003-290	MBA269772	
12	SH07-021-05-02	AIB4022_109_00131	PE ZAK 150X250 PLZ15B BINPAC	430	B003	7-5-2018 07:02	B003-1162	MBA268849	20-6-2018 08:11
13	SH07-005-01-02	AIB4022_109_00213	BAG MINIGRIP 40X60 MMTYPE 101	64	B002	31-8-2015 10:55	B002-2415	MBA00001	17-7-2017 07:42
14	SH05-001-14-01	AIB4022_110_00015	LABEL 6.35X6.35 THT-70-478-20	20000	B001	19-4-2017 15:14	B001-3238	MBA215146	7-6-2018 07:24
15	SH07-005-07-03	AIB4022_110_00341	LABEL THT-29-423-10 31X9MM	10000	B002	17-1-2017 15:52	B002-0279	MBA202395	16-5-2018 07:50
16	SH05-005-07-03	AIB4022_110_00548	STICKER THT-51-423-10 BRADY25.	20000	B002	28-8-2015 15:14	B002-2339	MBA00001	17-7-2017 07:40
17	SH02-006-04-02	AIB4022_110_00551	STICKER THT-46-478-10 BRADY	10000	B002	1-9-2015 13:37	B002-2511	MBA00001	18-5-2018 07:30
18	SH03-001-11-03	AIB4022_241_12371	STICKER 30X10MM WHITE 3M 7816	10000	B001	16-7-2018 13:06	B001-1509	MBA276993	
19	SH04-001-18-01	AIB4022_241_12371	STICKER 30X10MM WHITE 3M 7816	5000	B001	16-3-2018 09:02	B001-0186	MBA261190	16-7-2018 07:37
20	SH02-001-10-04	AIB4022_301_10091	LABEL THT-38-423-10 9.53X9.53	10000	B001	14-7-2015 15:46	B001-0729	MBA00001	17-7-2017 07:36
21	SH03-036-01-02	AIB4022_301_10491	SHIPPING STICKER ALFRED	10000	B005	6-7-2018 12:53	B005-0684	MBA043812	
22	SH01-017-09-01	AIB4022_301_10641	THERMOTRANSFERFOIL 90MMX300M	13	B003	7-9-2015 09:55	B003-0195	MBA00001	30-5-2018 08:09
23	SH07-004-08-04	AIB4022_301_10641	THERMOTRANSFERFOIL 90MMX300M	10	B002	6-4-2018 15:36	B002-2019	MBA264299	30-5-2018 07:13

Figure 19: Export from the VLM

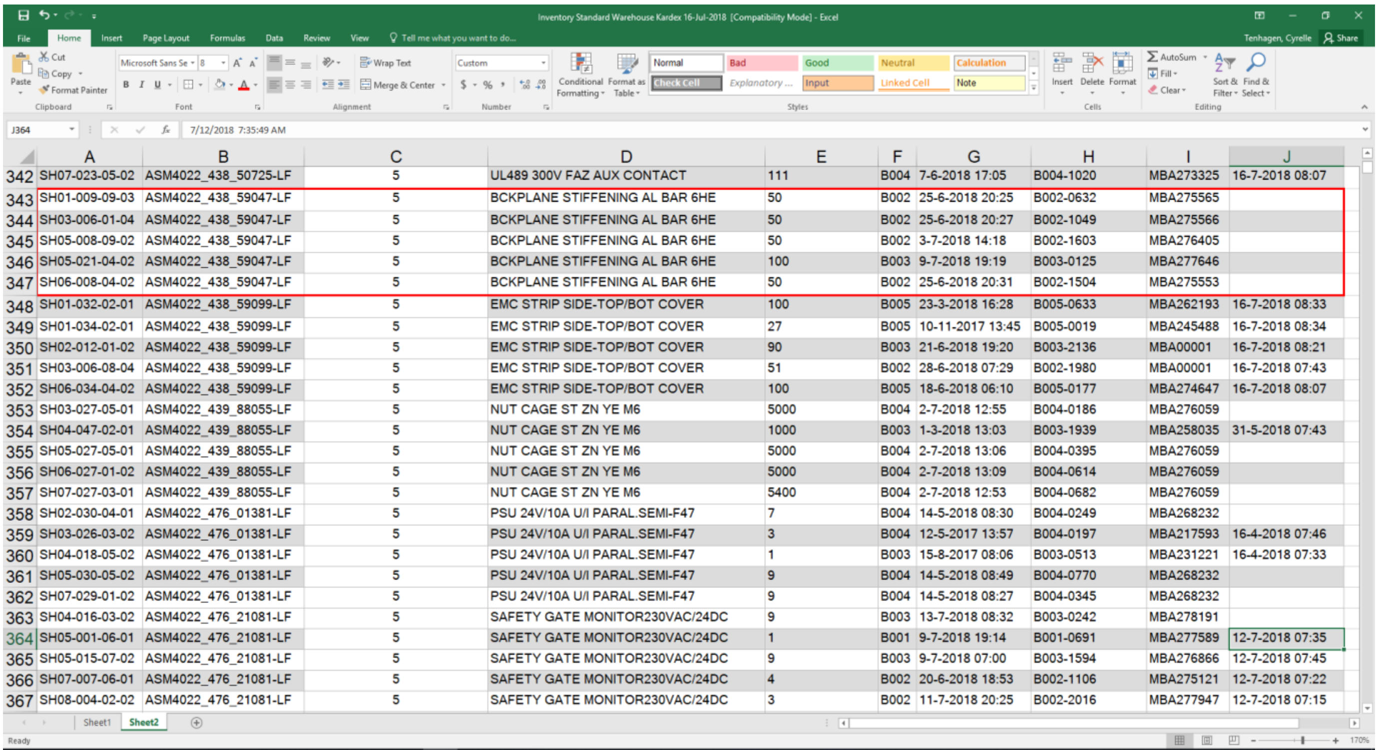
With help of the function CountIf or with help of a PivotTable, the parts ("Material" in column B) that occupy more than two bins can be returned. A filter is inserted to filter on the Material numbers that appear more than two times. These parts and corresponding information from other columns will be returned. See figure 20 for an example.

	A	B	C	D	E	F	G	H	I	J
1	Location	Material	Number of bins occupied	Information 1	Actual quantity	Bin	Date of storing	Processing unit	MBA no.	Count date
2	SH01-001-12-02	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	2	B001	7-5-2018 06:36	B001-0189	MBA268726	
3	SH01-046-17-04	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	1	B001	11-4-2018 06:36	B001-2446	MBA264728	
4	SH02-002-16-03	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	9	B001	14-5-2018 12:26	B001-0140	MBA269141	
5	SH03-002-07-02	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	2	B001	9-7-2018 06:57	B001-2376	MBA276859	
6	SH03-048-08-03	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	8	B001	24-4-2018 17:04	B001-3104	MBA267477	
7	SH04-001-08-03	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	6	B001	9-7-2018 19:23	B001-3603	MBA277588	
8	SH05-002-06-01	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	2	B001	9-7-2018 07:00	B001-3604	MBA276858	
9	SH06-011-12-03	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	6	B001	28-3-2018 06:44	B001-3206	MBA262505	
10	SH07-002-13-04	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	3	B001	9-7-2018 06:52	B001-3433	MBA276856	
11	SH07-003-04-02	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	4	B001	11-4-2018 16:54	B001-2620	MBA265209	
12	SH07-011-06-04	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	14	B001	18-6-2018 06:09	B001-3634	MBA274569	
13	SH07-011-08-04	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	5	B001	7-6-2018 17:44	B001-2507	MBA273040	
14	SH08-001-06-04	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	2	B001	4-6-2018 20:25	B001-1277	MBA272283	
15	SH08-001-07-02	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	2	B001	4-6-2018 20:25	B001-0104	MBA272280	
16	SH08-001-08-03	ASM4022_438_34921-LF	15	EYE CLAMP M6 X 16QMM	2	B001	4-6-2018 20:27	B001-1911	MBA272279	
17	SH01-002-15-04	THL3522_500_56588-LF	15	ESD-LABEL	150	B001	20-2-2017 15:40	B001-0984	MBA207284	23-4-2018 07:44
18	SH01-003-11-03	THL3522_500_56588-LF	15	ESD-LABEL	150	B001	20-2-2017 15:46	B001-2682	MBA207282	23-4-2018 07:45
19	SH01-046-16-04	THL3522_500_56588-LF	15	ESD-LABEL	100	B001	3-2-2017 15:42	B001-2719	MBA205150	23-4-2018 08:00
20	SH02-002-09-02	THL3522_500_56588-LF	15	ESD-LABEL	4	B001	14-2-2018 19:00	B001-2691	MBA257465	23-4-2018 07:43
21	SH04-001-20-03	THL3522_500_56588-LF	15	ESD-LABEL	211	B001	2-7-2018 14:57	B001-2414	MBA276214	
22	SH04-003-10-04	THL3522_500_56588-LF	15	ESD-LABEL	17	B001	1-2-2018 20:24	B001-0258	MBA255632	23-4-2018 07:21
23	SH04-003-13-01	THL3522_500_56588-LF	15	ESD-LABEL	7	B001	7-2-2018 18:48	B001-2806	MBA256497	23-4-2018 07:22
24	SH04-011-06-02	THL3522_500_56588-LF	15	ESD-LABEL	297	B001	14-6-2018 18:50	B001-0748	MBA274438	
25	SH05-003-09-01	THL3522_500_56588-LF	15	ESD-LABEL	313	B001	15-1-2018 18:53	B001-3355	MBA252929	23-4-2018 07:21
26	SH06-003-07-01	THL3522_500_56588-LF	15	ESD-LABEL	24	B001	22-2-2018 06:35	B001-3267	MBA258381	23-4-2018 07:25

Figure 20: Export from the VLM with filter, easy example

Based on the returned information, the company can decide which parts they want to relocate. In figure 20, you can see that the maximum number of bins one material occupies is 15 on July 16. All of these bins are type B001, while the quantity they contain is different. The highest quantity is 14 and the lowest is 1 (column "Actual Quantity"). Based on this information, it is clear that at least 14 parts fit in a B001 bin. This means that the number of bins could definitely be reduced when parts would be relocated for this part type.

Figure 20 showed an easy example where all parts are stored in type B001. In this example it is easy to tell that the parts could be divided over less bins. Unfortunately, this will not always be so likely. Another example where it is not easy to recognize if this is the case, based on the export only, is shown in figure 21.



	A	B	C	D	E	F	G	H	I	J
342	SH07-023-05-02	ASM4022_438_50725-LF	5	UL489 300V FAZ AUX CONTACT	111	B004	7-6-2018 17:05	B004-1020	MBA273325	16-7-2018 08:07
343	SH01-009-09-03	ASM4022_438_59047-LF	5	BCKPLANE STIFFENING AL BAR 6HE	50	B002	25-6-2018 20:25	B002-0632	MBA275565	
344	SH03-006-01-04	ASM4022_438_59047-LF	5	BCKPLANE STIFFENING AL BAR 6HE	50	B002	25-6-2018 20:27	B002-1049	MBA275566	
345	SH05-008-09-02	ASM4022_438_59047-LF	5	BCKPLANE STIFFENING AL BAR 6HE	50	B002	3-7-2018 14:18	B002-1603	MBA276405	
346	SH05-021-04-02	ASM4022_438_59047-LF	5	BCKPLANE STIFFENING AL BAR 6HE	100	B003	9-7-2018 19:19	B003-0125	MBA277646	
347	SH06-008-04-02	ASM4022_438_59047-LF	5	BCKPLANE STIFFENING AL BAR 6HE	50	B002	25-6-2018 20:31	B002-1504	MBA275553	
348	SH01-032-02-01	ASM4022_438_59099-LF	5	EMC STRIP SIDE-TOP/BOT COVER	100	B005	23-3-2018 16:28	B005-0633	MBA262193	16-7-2018 08:33
349	SH01-034-02-01	ASM4022_438_59099-LF	5	EMC STRIP SIDE-TOP/BOT COVER	27	B005	10-11-2017 13:45	B005-0019	MBA245488	16-7-2018 08:34
350	SH02-012-01-02	ASM4022_438_59099-LF	5	EMC STRIP SIDE-TOP/BOT COVER	90	B003	21-6-2018 19:20	B003-2136	MBA00001	16-7-2018 08:21
351	SH03-006-08-04	ASM4022_438_59099-LF	5	EMC STRIP SIDE-TOP/BOT COVER	51	B002	28-6-2018 07:29	B002-1980	MBA00001	16-7-2018 07:43
352	SH06-034-04-02	ASM4022_438_59099-LF	5	EMC STRIP SIDE-TOP/BOT COVER	100	B005	18-6-2018 06:10	B005-0177	MBA274647	16-7-2018 08:07
353	SH03-027-05-01	ASM4022_439_88055-LF	5	NUT CAGE ST ZN YE M6	5000	B004	2-7-2018 12:55	B004-0186	MBA276059	
354	SH04-047-02-01	ASM4022_439_88055-LF	5	NUT CAGE ST ZN YE M6	1000	B003	1-3-2018 13:03	B003-1939	MBA258035	31-5-2018 07:43
355	SH05-027-05-01	ASM4022_439_88055-LF	5	NUT CAGE ST ZN YE M6	5000	B004	2-7-2018 13:06	B004-0395	MBA276059	
356	SH06-027-01-02	ASM4022_439_88055-LF	5	NUT CAGE ST ZN YE M6	5000	B004	2-7-2018 13:09	B004-0614	MBA276059	
357	SH07-027-03-01	ASM4022_439_88055-LF	5	NUT CAGE ST ZN YE M6	5400	B004	2-7-2018 12:53	B004-0682	MBA276059	
358	SH02-030-04-01	ASM4022_476_01381-LF	5	PSU 24V/10A U/I PARAL.SEMI-F47	7	B004	14-5-2018 08:30	B004-0249	MBA268232	
359	SH03-026-03-02	ASM4022_476_01381-LF	5	PSU 24V/10A U/I PARAL.SEMI-F47	3	B004	12-5-2017 13:57	B004-0197	MBA217593	16-4-2018 07:46
360	SH04-018-05-02	ASM4022_476_01381-LF	5	PSU 24V/10A U/I PARAL.SEMI-F47	1	B003	15-8-2017 08:06	B003-0513	MBA231221	16-4-2018 07:33
361	SH05-030-05-02	ASM4022_476_01381-LF	5	PSU 24V/10A U/I PARAL.SEMI-F47	9	B004	14-5-2018 08:49	B004-0770	MBA268232	
362	SH07-029-01-02	ASM4022_476_01381-LF	5	PSU 24V/10A U/I PARAL.SEMI-F47	9	B004	14-5-2018 08:27	B004-0345	MBA268232	
363	SH04-016-03-02	ASM4022_476_21081-LF	5	SAFETY GATE MONITOR230VAC/24DC	9	B003	13-7-2018 08:32	B003-0242	MBA278191	
364	SH05-001-06-01	ASM4022_476_21081-LF	5	SAFETY GATE MONITOR230VAC/24DC	1	B001	9-7-2018 19:14	B001-0691	MBA277589	12-7-2018 07:35
365	SH05-015-07-02	ASM4022_476_21081-LF	5	SAFETY GATE MONITOR230VAC/24DC	9	B003	9-7-2018 07:00	B003-1594	MBA276866	12-7-2018 07:45
366	SH07-007-06-01	ASM4022_476_21081-LF	5	SAFETY GATE MONITOR230VAC/24DC	4	B002	20-6-2018 18:53	B002-1106	MBA275121	12-7-2018 07:22
367	SH08-004-02-02	ASM4022_476_21081-LF	5	SAFETY GATE MONITOR230VAC/24DC	3	B002	11-7-2018 20:25	B002-2016	MBA277947	12-7-2018 07:15

Figure 21: Export from the VLM with filter, difficult example

In figure 21, the parts marked in red are divided over five different bins of type B003 and B002. B003 is bigger than B002, and B003 is the only one that occupies 100 parts. The B002 bins all occupy 50 parts. It is not easy to say if the number of bins could be reduced in this case. Physical checking of the content of these bins is necessary to find out if the parts could be divided over less bins.

c. Visually checking if bins can store more parts

The last approach is to visually check whether bins can store more parts. This option is very time consuming, because the warehouse employee has to go through all plateaus to see if there are bins with free space to store more parts. However, the work instruction “Items overpakken van grote naar kleine bak (Kardex)” that was made to place parts from a certain bin to a smaller bin, is applying this approach.

When this approach is chosen, it is recommended to use the list with superfluous bins from approach 2 (export from inventory in the VLM), so that not every bin has to be checked.

7.4 Implementing class-based storage assignment

In the literature review, the class-based storing method with random allocation of bins within classes appeared to be the best way to optimize space utilization and travel times in the VLM. The five following steps are determined to be important for achieving class-based storage assignment.

Step 1: Determine the types of classes for parts

The method that scored best in the AHP was the MC ABC classification (section 6.4). In this classification method, parts can be placed in three different classes, A, B, and C. These classes are based on criteria that are important for Benchmark. Benchmark has to establish these criteria themselves.

Step 2: Place all parts within a class

Now the classes of the MC ABC are clear, all parts have to be placed inside a class. The number of parts that can be placed in a certain class has to be determined by the company.

Step 3: Determine the best locations for the classes in the VLM system

To be able to apply the MC ABC classification method inside the VLM, three different zones have to be created. How these three different zones are spread over the modules depends on the preferences of the company. To decide how to spread the classes, the company first has to be establish how many parts have to be located in every class. An example of dividing the classes is to assign class A (important) to the lowest three plateaus in figure 22, class C to the ten plateaus at the top and the rest of the plateaus in-between A and C. When Benchmark choses to implement the solution on the obsolete category only, C could be used to place these bins.

Figure 22: Schematic picture of VLM (https://lib.ugent.be/fulltxt/RUG01/001/418/553/RUG01-001418553_2010_0001_AC.pdf

Step 4: Relocate bins currently not located in the desired zone to the desired zone

Relocating bins is necessary to make the class-based storing strategy succeed. After performing steps 1, 2, and 3, the relocation of bins can be executed by performing the plan in section 7.2 and with help of one of the three approaches described in section 7.3.

Step 5: Maintaining the strategy

To let the class-based storing method be successful over time, the locations of bins have to be checked once in a while.

Conclusion

This chapter is devoted to the implementation of the solution. This is part of the Do step in the PDCA-cycle. Two implementation plans are presented about how to perform the placing of identical parts into fewer bins while maintaining FIFO picking. Furthermore, an implementation plan is presented about implementing the class-based storing method. The remaining steps of the PDCA-cycle have to be performed by the company itself after deciding which solution to implement. These steps are the Check to check whether the intended results are achieved and Act to transform the improvement into a routine.

8. Discussion of possibilities

8.1 Optional solutions

The performed literature review did not find many possibilities to reduce the number of superfluous bins inside a VLM by the ways the research goal of this thesis requires. The three possibilities by which the research goal can be achieved is by placing identical parts in fewer bins, placing different parts in fewer bins, or implementing a new type of adjustable bins. All options are designed to enable FIFO picking based on MBA-number. The first two options can be performed with help of two approaches. The first is to locate parts in fewer bins in the storing stage and the second to relocate parts over fewer bins once every couple of weeks.

All possibilities have its own pros and cons, but can reduce the number of superfluous bins from 9% to 0%. To find out the opinion of employees of the company about the possibilities to reduce the number of superfluous bins, the following options were proposed:

1. Refilling bins in the VLM with identical parts in the storing stage
2. Relocating parts from multiple bins to fewer bins, once in a couple of weeks
3. Refilling bins in the VLM with different parts in the storing stage
4. Inserting adjustable bin sizes, with or without use of dividers

Locating different kinds of parts within fewer bins immediately fell of, because employees did not like this option at all. The use of a new type of adjustable bins also received a relatively low score. However, it is a good option to keep track of different MBA-numbers within one bin. More locations can be created and the procedure to store one MBA-number in one location can be maintained. Disadvantages of this option are that investments are required and the way of working for employees changes relatively heavy compared to the other three.

8.2 Remaining solution

Option 1 and option 2 gained relatively higher scores than the other two. In chapter 4, possibilities 1 and 2 were generalized as one option: Reducing the number of bins per part by placing identical parts in fewer bins, with FIFO picking based on MBA-number. The two options are generalized, because the results of both options are the same. In both cases, identical parts will be divided over fewer bins. The implementation of the options is the only thing that differs. To provide more insight in the performance of these two options, an implementation plan for both was provided in chapter 7. The score employees give to each approach could possibly change after reading the implementation plan, since the explanation they received initially was not very extended.

Refilling bins in the VLM with identical parts in the storing stage or relocating parts once in a few weeks are both good possibilities to achieve the research goal. The option to relocate parts was rated a bit higher by employees, though difference between the scores was not significant. Furthermore, refilling bins in the VLM requires more work on forehand, while the second option requires more work to maintain.

In the first option, dimensions of every location and dimensions of all parts have to be entered in Baan. When this has happened, the tasks to maintain the plan exist of letting PowerPick search for bins in the VLM with identical parts and consequently to let a warehouse employee search in Baan for bins that can store more parts. Relocating parts requires less work on forehand, since locations and dimensions of parts do not have to be entered into Baan per se. Visually checking content of bins and using an export from PowerPick can provide sufficient information about the content of bins. However, this data is less specific than when Baan would determine the content that could be added to occupied bins. Besides, visually checking of content of bins or developing an export takes time, and time is considered valuable in warehousing processes according to multiple warehouse employees. Refilling bins provides more peace in the performance of processes over time, due to obtained consistency of the new receiving and storing procedure. Relocation on the other hand requires less work on forehand and changes nothing in the current storing procedure initially.

8.3 Discussion of how to apply FIFO

Applying FIFO picking is not necessary for all parts, but it is recommended to be able to find out the batch lots of parts afterwards. How to apply FIFO is not elaborated in this thesis. The most obvious way to apply it is assumed to be labelling every separate box or plastic bag instead of only one label per bin. The use of adjustable bin sizes does not require this, but employees rated this option relatively low. There are more alternatives to apply FIFO within the bins that are not treated, for example by using colored stickers or by placing new parts left and older ones on the right side. The disadvantage of applying an alternative option for distinguishing parts within one bin is that the MBA-number is more difficult to figure out afterwards. Besides, the current approach to label parts works sufficient. For these reasons, other ways of applying FIFO were not studied.

8.4 Storage assignment methods

The warehouse manager indicated in a conversation, after discussing some possibilities, that he thought placing identical parts into fewer bins was not a good idea. He thought this decreases efficiency of warehousing processes. Due to these insecurities about changing the storing process, literature research has been performed to ways to increase efficiency by means of space utilization and travel times of the system.

The results of the literature review showed that the current storage assignment policy is not the most optimal one. Not right now and not after implementing the solution. Literature shows that of the six mostly applied methods in both AS/RS systems in general and VLM in particular, class-based assignment results in the lowest travel times when using an appropriate number of classes. Full-turnover based storage also showed good results, though this method requires knowledge about turnover rates and may need relocation of parts once in a while. Random assignment showed the best results in space efficiency. When applying the class-based method with random allocation within classes, both space utilization and travel times can be optimized. Low travel times can particularly be obtained by locating bins with parts of a certain (important) class closer to the I/O point. The literature review to VLM systems found that an AS/RS in general fairly differs from a VLM due to single or multiple command transactions instead of dual command. Therefore, locating bins with parts that have to be picked at the same time are preferred to be stored close together. The Order Oriented Slotting method stores parts from the same order close together, and this way requires the VLM to have lower travel times. The results of this method compared to random allocation can be seen in figure 17.

When comparing the class-based storage assignment methods to a previously performed thesis at Benchmark, the AHP shows that the class-based storage assignment method scores better than the optimal method according to the thesis on every criteria. When the company decides not to implement one of the provided possibilities to reduce the number of superfluous bins, changing the current storage assignment policy could still decrease travel times in the VLM. A downside of this choice is that the goal of this study cannot be achieved.

8.5 Classification methods

Eight classification methods were compared in this thesis. Four of them are currently applied in the company and the other four are the most studied and successful ones according to scholars. All classification methods are rated on five criteria, with help of the AHP. The criteria take into consideration the travel times and space utilization in the VLM, and take into account the level by which each method can succeed in the company. The method that scored best in the AHP is the MC ABC classification, with a score of 79. Although the MC ABC classification scored best, Order Oriented Slotting also provides good results with a score of 76. The reason this classification method scores less is due to the fact that the content of orders changes often at Benchmark, causing the chance of having to relocate bins to increase.

9. Conclusion, recommendations and limitations

9.1 Conclusion

The goal of the solution for this study is to decrease the number of superfluous bins by storing parts within fewer bins. This is a way to increase space efficiency in Kardex ZKDX1001. The solution that scored best according to opinions from employees of the company is to place identical parts in fewer bins, while enabling FIFO picking based on MBA-number. This solution can reduce the percentage of superfluous bins to zero by refilling bins in the VLM with identical parts in the storing stage or by relocating parts from multiple bins to fewer bins, once in a couple of weeks. For both practices, an implementation plan is presented in chapter 7, to give the company more insight in which option they prefer. A requirement for both performance possibilities is to be able to put more than one MBA-number inside a bin, which is not possible with the current software. Once the software is adjusted, locating parts into fewer bins in the storing stage provides higher consistency than the option to relocate parts. In the first option, the warehousing processes will change a bit as visualized with help of two process flows. Once all work that has to be performed on forehand is finished, it is just a matter of time to let workers get used to the new way of working. When the company wants their (warehouse) employees to be positive about the implementation, they are recommended to insert the first implementation plan due to consistency of this option. If the company does not want to spend all this time on forehand, relocating parts would be the best alternative. Which would not be a surprising choice, since time is considered valuable in the warehouse according to employees.

This thesis is also providing a possibility to (re)locate a selection of parts, which can simplify the implementation. Obsolete parts make little movements in the VLM over time. Only (re)locating obsolete parts to fewer bins could currently decrease 88 of the superfluous bins in the VLM. What has to be kept in mind is the effect of this alternative on the picking process. Picking most of the time occurs from locations that contain active parts. Obsolete parts are non-active. This means that relocating only obsolete parts has little influence on the number of bins a picker has to pick parts from to complete one workorder. The reduction in total picking time increases when more active parts would be divided over less bins.

The best results in space efficiency in the VLM while keeping travel time low can be achieved by implementing the class-based storage assignment method with random allocation, according to articles studied in the literature review. For both implementation plans, a decrease in travel time may be required to create extra time. Even when none of the plans is implemented, inserting the class-based storage assignment method improves efficiency by reducing travel times in the VLM.

When the class-based storage assignment method is implemented within the VLM, a classification method is required to enable parts to be assigned to different zones in the VLM. The MC ABC classification method with a score of 79 is the best option, according to AHP. When inserting the MC ABC classification method, Benchmark can decide which criteria are important to take into consideration when dividing parts over classes A, B, and C. Parts in class A could be placed closer to the I/O point and parts in class C can be located higher in the VLM. This allows travel times to decrease. Since random allocation shows the best results in efficiency in space utilization, applying this within the classes of the class-based method shows the best results compared to other storage assignment methods.

9.2 Recommendations

The chosen focus of this study is to decrease the number of superfluous bins by dividing identical parts over fewer bins. No matter what choice the company makes about the solution, it is recommended to investigate the purchasing procedures that are currently applied. Order dates and order quantities could be optimized, which can significantly influence the number of superfluous bins.

Another way to decrease the number of superfluous bins is to have a more accurate insight in demand of the customers. Customers are contractually allowed to change demand, which is not going to be modified in the nearby future according to the purchase manager. However, deliberating with the customer about changing demand could help to get a more reliable forecast of demand. When it appears that customers are able to give a better indication of their demand, unnecessary procurements could be prevented. As a result, the number of superfluous bins could be reduced.

When Benchmark chooses to implement the solution, Kaizen recommends to walk through the additional steps of the PDCA-cycle. Due to the duration of this research this was not possible. Performing steps C and A is necessary to finish the steps for continuous improvement and let the effect of the improvement be at the best.

When Benchmark chooses to not implement the solution, the company could still improve efficiency in warehousing processes by changing the current storage assignment policy. The class-based storage assignment with random allocation within classes decreases travel times of the VLM while maintaining space efficiency.

Data about obsolete parts found that many parts in the warehouse did not move for a long time. The company could decide to relocate identical, obsolete parts to fewer bins or to remove them from the VLM. In the duration of the study, obsolete parts received some attention because the current approach by which Benchmark copes with them is far from optimal. In appendix 10.5, all findings about bins containing obsoletes are shortly discussed. It is recommended to take a look to this information.

9.3 Limitations

The performance of this thesis has several limitations, these limitations are listed below:

- The calculation that was made in chapter one is an approximation, since it is not sure if the total number of parts of one part type fits within two bins;
- When the company chooses to only (re)locate bins containing obsolete parts, the number of superfluous bin cannot be reduced from 9 to 0%;
- The current PowerPick software is not able to batch more than one MBA-number to a location. For both implementation plans this option is required;
- Additional costs of the implementation plans were not taken into consideration, since they are assumed to have little influence on the preferred solution of the company.

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10. Appendix

10.1 MPSM Phase one: Problem identification

Problem cluster

A problem cluster functions as a model of the problem situation. All problems that were recognized to influence the warehouse getting overfull are noticed as actions problems. All action problems are depicted in figure 2 (also in chapter 1). The problems are causally related with arrows going from cause to effect.

Figure 2: Problem cluster

Core problem

The core problem is the action problem from the problem cluster that is chosen as the problem to be solved during the project. The core problem cannot be caused by another noticed problem, returning five possible core problems in this case. Talking to different stakeholders of Benchmark, made me choose the following action problem as core problem:

"Vertical Lift Module stores parts within a new bin every time a delivery order arrived"

In the problem cluster, this problem is one of the five problems without causation by another problem. This means that there are five possible core problems according to the MPSM. Solving the chosen core problem will have most influence on satisfying Benchmark in my opinion. The reason of my choice will be explained in the motivation on the next page.

Motivation of core problem
Benchmark declared that their warehouse is overfull. In the problem cluster can be found that one cause of this problem is the increasing demand. Increasing demand is a problem that should not be solved, since increasing demand means Benchmark is doing good business. Another cause can be found in products that are stored in the warehouse for too long. Two core problems are causing this problem, namely purchasers ordering too early and purchasers ordering too many products. These are important problems that would be useful to solve. I had to make a choice between solving one of these two problems or solving problem the core problem. Since the last took more of my interest, I will be solving this problem. Nevertheless, I recommend Benchmark to investigate the other two problems in the future.

The last problem is the warehouse not being used efficiently. This is caused by two core problems, namely the Vertical Lift Module (VLM) is currently storing parts and products in random places and there is no clear procedure for storing products. Parts in the VLM system are stored inside bins (see figure 2). The size of the bin determines the location the bin will be placed. The randomness of the storing method is caused by the FIFO method Benchmark desires to apply. This means that incoming goods that are exactly the same but did not arrive at the same moment, are stored at different locations in the VLM. One type of part can occupy for example nine bins of space in the VLM, of which all bins are just filled half. Benchmark chose this procedure to be able to apply the FIFO method, which is by nobody confirmed to be necessary. The other cause of inefficiency in storing is that Benchmark does not use procedure(s) for storing products in the warehouse.

My focus will be on storing in the dynamic VLM system instead of the procedure for storing products as a whole. The reason for this is the diversity of the products. Since the warehouse is storing products with great variety, investigating a procedure would take a lot of time and not fit into the ten weeks of my bachelor project.

Norm and reality of the core problem
The core problem is found, but not clear enough. To clarify the goal of the project, the description of the norm and reality has to be clear and concise. This is treated in chapter 1 of this thesis.

Around 20 percent of the bins in the VLM systems of the main warehouse is in use by one part type that is assigned to more than two locations, causing unnecessary space of the VLM to be filled

Continuing MPSM
In this thesis, the MPSM is applied as a guideline to come to the solution of this project. The following phases are part of the MPSM. All phases are went through in this project:

1. Identification of the problem
2. Formulating problem approach
3. Analyzing problem
4. Formulating alternative solutions
5. The decision
6. The implementation
7. The evaluation

10.2 Classifying parts

a. Item group codes

Item Group	Description
10000	010000 ASM, BOX UNIT
20000	020000 ASM, CCA,GENERIC (TEST)
21000	021000 ASM, CCA, CPU (TEST)
22000	022000 ASM, CCA, K-IOP (TEST)
23000	023000 ASM, CCA, MEM (TEST)
24000	024000 ASM, CCA, PCI (TEST)
25000	025000 ASM, CCA, K-IOAI (TEST)
100000	100000 ASM, FINISHED ASSEMBLY
101000	101000 ASM, SUB-ASSEMBLY
102000	102000 IC, PROGRAMMED (MFG)
103000	103000 IC, PROGRAM AT TEST
104000	104000 RMA ITEMS
110000	110000 ASM, DISK DRIVE
111000	111000 ASM, PHANTOM
112000	112000 SUB-CONTRACT
113000	113000 ASM, CCA, POWER
114000	114000 SUITCASE (CPU/MEM)
115000	115000 ASM, CABINET
116000	116000 ASM, LABEL
150000	150000 ASM, CONFIGURED
160000	160000 ASM, BASIC SYS, BUILD
170000	170000 ASM, PROTOTYPE
180000	180000 ASM, KIT
181000	181000 ASM, KIT- CUST SPECIFIC
182000	182000 ASM, KIT- CUST SPECIFIC
183000	183000 MANUFACTURED COMPONENT
200000	200000 ASM, PURCHASED OUTSIDE
201000	201000 PCB, GENERIC
201100	201100 PCB, SINGLE/DOUBLE SIDE
201200	201200 PCB, MULTI-LAYER
201300	201300 PCB, NON-FIBERGLASS
202000	202000 ASM, TERMINAL
203000	203000 ASM, CDROM DRIVE
204000	204000 ASM, MODEM
205000	205000 ASM, NODE
206000	206000 ASM, PERIPHERAL
210000	210000 ASM, CCA, CPU
220000	220000 ASM, CCA, K-IOP
230000	230000 ASM, CCA, MEM
240000	240000 ASM, CCA, PCI
250000	250000 ASM, CCA, K-IOA
280000	280000 ASM, KIT (PURCHASED)
301000	301000 IC, GENERIC
301100	301100 IC, LINEAR
301200	301200 IC, STANDARD LOGIC
301300	301300 IC, MEMORY (RAM)
301400	301400 IC, CUSTOM (ASIC)
301500	301500 IC, MICROCONTROLLER
301600	301600 IC, PROGRAMMABLE
301700	301700 IC, PROGRAMMED (PURCH)
320000	320000 IC, PROGRAMMED (PURCH)
400000	400000 RESISTORS
401000	401000 CAPACITORS
402000	402000 INDUCTORS
403000	403000 TRANSFORMERS
404000	404000 FILTERS, HYBRIDS
405000	405000 DIODES
406000	406000 TRANSISTORS
407000	407000 POWER SEMICONDUCTORS
408000	408000 OPTOELEC, LEDS, DISPLAY
409000	409000 FUSES, CIRCUIT BREAKERS
410000	410000 CRYSTALS, OSCILLATORS
411000	411000 BATTERIES
412000	412000 RELAYS, SOLENOIDS
413000	413000 SWITCHES
414000	414000 AUDIO
415000	415000 SENSORS
416000	416000 LABELS/PRINT MATL
417000	417000 SUPP, PROCESS
418000	418000 SUPP, PKG
418100	418100 SUPP, PKG
419000	419000 SUPP, LABELS/MISC
419100	419100 MANUALS/TECH PUBS
419200	419200 DOCS(NON-MANUAL/TECH PU

420000	420000 POWER SUPPLIES
430000	430000 SOFTWARE, GENERIC
430100	430100 SOFTWARE,FTX,HPUX,VOS,N
430200	430200 SOFTWARE,(NON-FTX,HPUX,
450000	450000 CONNECTORS
451000	451000 SOCKETS
452000	452000 WIRE & TUBING
452100	452100 WIRE & TUBING
453000	453000 CABLE ASSEMBLY
454000	454000 CBL ACC/GSKT/SEALS/INSU
460000	460000 HARDWARE, GENERIC
460100	460100 HARDWARE, FASTENERS
460200	460200 HARDWARE, PLASTICS
460300	460300 HARDWARE, METALS
460400	460400 HARDWARE, HEATSINKS
460500	460500 HARDWARE, GLASS
470000	470000 RAW MATERIALS
600000	600000 SUPP, EXP PROCESS
601000	601000 SUPP, EXP PKG
602000	602000 SUPP, LABELS/MISC
603000	603000 FIXTURE/TOOLING (PURCH)
610000	610000 MAINTENANCE SPARE PARTS
850000	850000 NRE -CHARGE TO CUSTOMER
860000	860000 GEN LEDGER NRE CUST PO
870000	870000 PROTOTYPE PURCHASES
880000	880000 SUB-CONTRACT
891000	891000 SUPP, PROCESS (NON-INV)
892000	892000 SUPP, EXP PKG (NON-INV)
893000	893000 SUPP, OFFICE (NON-INV)
894000	894000 FIXTURES/TOOLING (COST)
896000	896000 TEST EQUIPMENT (COST)
899000	899000 GEN LEDGER COST ITEMS

b. Value class codes

A1: This classification is intended for use with purchased components with a high extended usage value. These parts should be ordered and controlled on a frequent basis. Parts in the top 80% of the division's spend should be categorized at this value class and the recommended order interval is 5 days.

B1, C1, D1: These classifications are set up to allow the site some flexibility in setting up the order intervals for items with extended usage value that falls between the A1 and E1 category. Depending on the value of the extended usage, these ranges can be set at different clip levels to drive the correct ordering patterns. Typical expected ranges are included below.

E1: This classification is intended for use with purchased components with a very low extended usage value. These parts should be ordered and controlled on the least frequent basis as there is little inventory exposure to the company. Parts in the bottom 2% of the division spend should be categorized at this value class and the recommended order interval is 85 days.

NC: Parts that are non-cancelable and non-returnable are to be identified separately and handled with a high degree of control. These parts are recommended to be set at an order interval of 5 days. Parts flagged in general item data, supplemental data II, with NCNR box checked will automatically be set to NC. In certain circumstances where the extended usage value is extremely low, sites may elect to increase the order interval. These situations should be reviewed and evaluated on a case by case basis to limit inventory exposure.

NP: Parts with no demand in the time horizon selected will be set to NP. Recommended order interval for these components is 20 days. Parts with demand and no standard cost will also be set as NP. It is recommended that divisions review these parts in detail so that the appropriate setting can be updated as soon as possible.

X1: This value class is intended for extremely sensitive component purchases that need to be controlled on a day by day basis. Recommended order interval for this category is 1 – 5 days. Parts in this category will need to be manually set by the division.

Y1: This value class is intended for component purchases that are bulky and need to be controlled due to physical warehousing constraints. Parts of this nature are often set up on a Just in Time basis for daily or weekly delivery. Recommended order interval for this category is 1-20 days. Parts in this category will need to be manually set by the division.

S1: This value class is for items that have been set in Baan for order system SIC. These items are controlled through re-order points and are excluded from the value class calculations and updates.

c. Signal codes

Code	Explanation
NPR	Not yet in production
NPI	Can be used in production, but not yet serial production
CRT	Critical parts, for prototyping and not yet serial production
FAI	First Article Inspection, not yet serial production
POU	Part is phased out, new version is coming
PIN	Part is phased in, the new version of POU
" " (blank)	Active and normal item
INA	No inventory movement for more than half a year, properly check before changing code (part can be needed for products that are produced once in two years)
LTB	Last Time Buy: Pre-alert for part that cannot be bought anymore
EOL	End of Life: For assembly that is no longer built
OBS	No longer in use, no demand and no inventory
RVS	Item that was obsolete, but now again has demand

10.3 Entering dimensions of parts in Baan

Click in the first window of Baan the “General Item Data”.

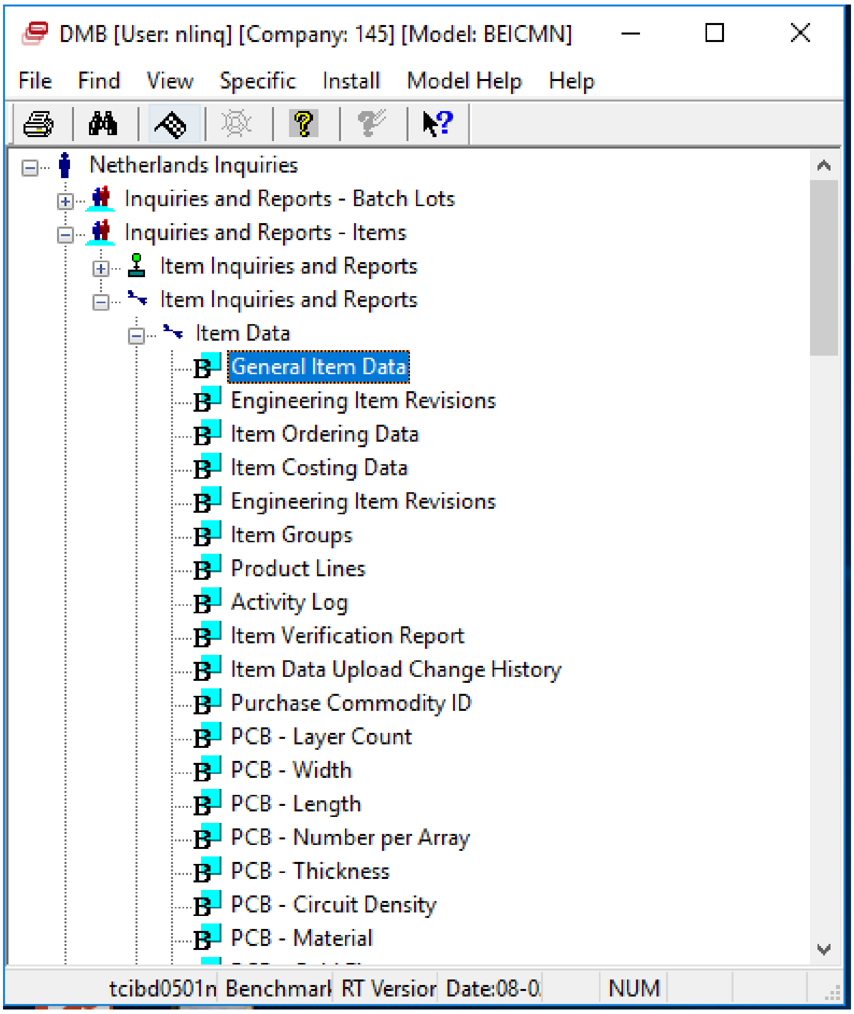


Figure 23: First window of Baan

In the window that pops up, click the item you want to give dimensions to. The window in the front of figure 24 will then appear. Here you click on the "Supp Data II" button.

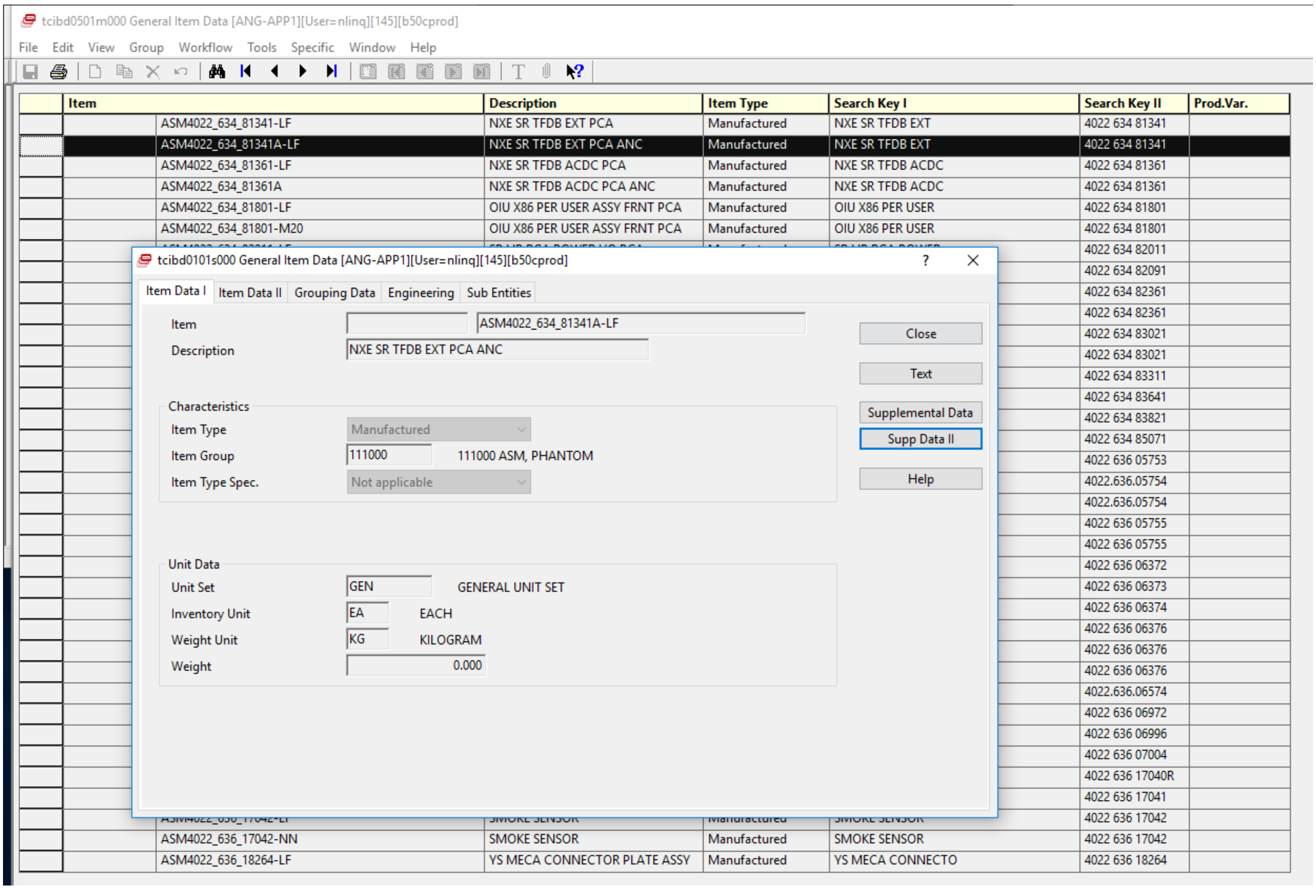


Figure 24: General Item Data in Baan

Now the window in figure 25 pops up. Here you can enter all dimensions that you would like to let Baan know.

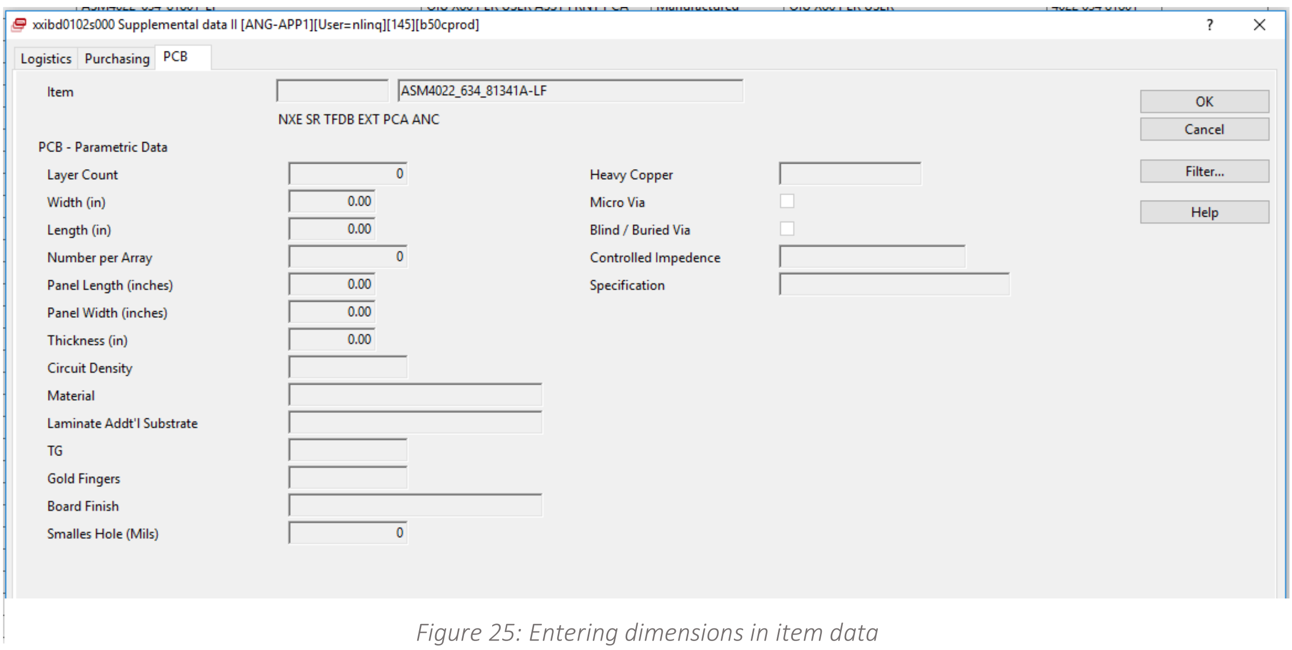


Figure 25: Entering dimensions in item data

10.4 Entering dimensions of locations in Baan

In the first window of Baan, click "Locations".

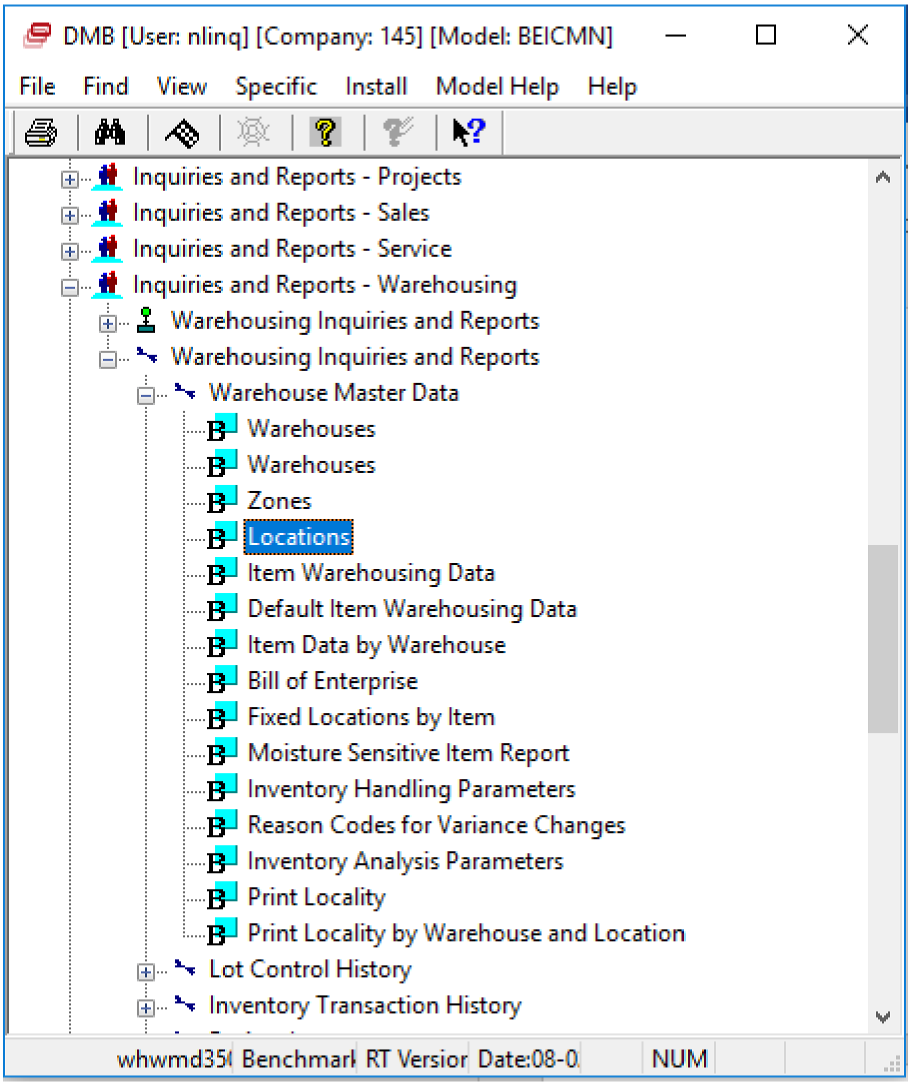
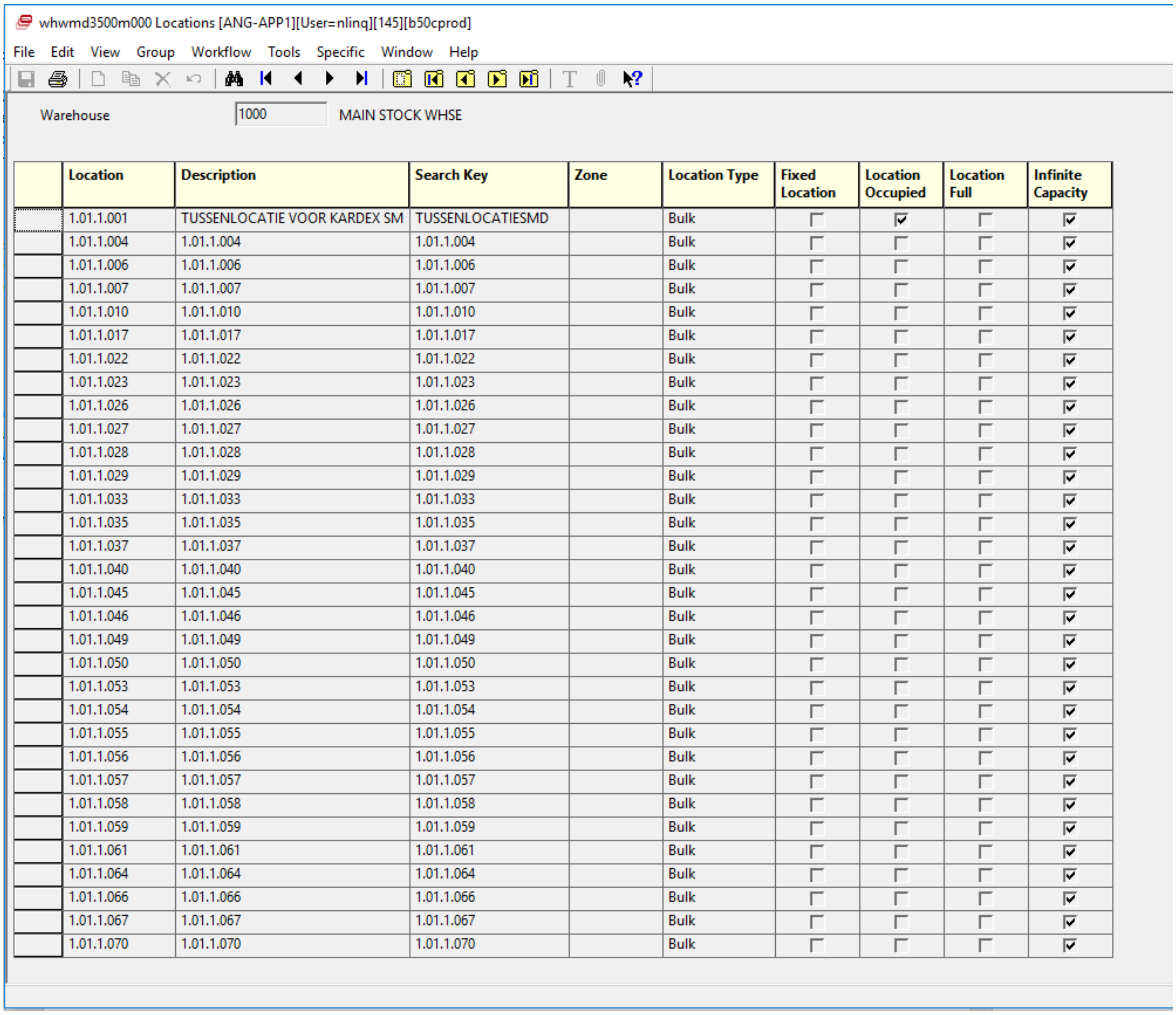


Figure 26: First window in Baan

The window in figure 27 appears. Here you see all the locations that are currently available. At the moment, the only locations for the Kardex systems in the main warehouse are ZKDS1001 (location between receiving and storing) and ZKDX1001.



Location	Description	Search Key	Zone	Location Type	Fixed Location	Location Occupied	Location Full	Infinite Capacity
1.01.1.001	TUSSENLOCATIE VOOR KARDEX SM	TUSSENLOCATIESMD		Bulk	☐	☑	☐	☑
1.01.1.004	1.01.1.004	1.01.1.004		Bulk	☐	☐	☐	☑
1.01.1.006	1.01.1.006	1.01.1.006		Bulk	☐	☐	☐	☑
1.01.1.007	1.01.1.007	1.01.1.007		Bulk	☐	☐	☐	☑
1.01.1.010	1.01.1.010	1.01.1.010		Bulk	☐	☐	☐	☑
1.01.1.017	1.01.1.017	1.01.1.017		Bulk	☐	☐	☐	☑
1.01.1.022	1.01.1.022	1.01.1.022		Bulk	☐	☐	☐	☑
1.01.1.023	1.01.1.023	1.01.1.023		Bulk	☐	☐	☐	☑
1.01.1.026	1.01.1.026	1.01.1.026		Bulk	☐	☐	☐	☑
1.01.1.027	1.01.1.027	1.01.1.027		Bulk	☐	☐	☐	☑
1.01.1.028	1.01.1.028	1.01.1.028		Bulk	☐	☐	☐	☑
1.01.1.029	1.01.1.029	1.01.1.029		Bulk	☐	☐	☐	☑
1.01.1.033	1.01.1.033	1.01.1.033		Bulk	☐	☐	☐	☑
1.01.1.035	1.01.1.035	1.01.1.035		Bulk	☐	☐	☐	☑
1.01.1.037	1.01.1.037	1.01.1.037		Bulk	☐	☐	☐	☑
1.01.1.040	1.01.1.040	1.01.1.040		Bulk	☐	☐	☐	☑
1.01.1.045	1.01.1.045	1.01.1.045		Bulk	☐	☐	☐	☑
1.01.1.046	1.01.1.046	1.01.1.046		Bulk	☐	☐	☐	☑
1.01.1.049	1.01.1.049	1.01.1.049		Bulk	☐	☐	☐	☑
1.01.1.050	1.01.1.050	1.01.1.050		Bulk	☐	☐	☐	☑
1.01.1.053	1.01.1.053	1.01.1.053		Bulk	☐	☐	☐	☑
1.01.1.054	1.01.1.054	1.01.1.054		Bulk	☐	☐	☐	☑
1.01.1.055	1.01.1.055	1.01.1.055		Bulk	☐	☐	☐	☑
1.01.1.056	1.01.1.056	1.01.1.056		Bulk	☐	☐	☐	☑
1.01.1.057	1.01.1.057	1.01.1.057		Bulk	☐	☐	☐	☑
1.01.1.058	1.01.1.058	1.01.1.058		Bulk	☐	☐	☐	☑
1.01.1.059	1.01.1.059	1.01.1.059		Bulk	☐	☐	☐	☑
1.01.1.061	1.01.1.061	1.01.1.061		Bulk	☐	☐	☐	☑
1.01.1.064	1.01.1.064	1.01.1.064		Bulk	☐	☐	☐	☑
1.01.1.066	1.01.1.066	1.01.1.066		Bulk	☐	☐	☐	☑
1.01.1.067	1.01.1.067	1.01.1.067		Bulk	☐	☐	☐	☑
1.01.1.070	1.01.1.070	1.01.1.070		Bulk	☐	☐	☐	☑

Figure 27: Locations window in Baan

10.5 Obsolete parts

The number of unnecessary, obsolete bins is already given in section 6.3. In this section, it was determined that the maximum reduction of unnecessary, obsolete bins, considering reduction to one bin per part, is 88. Returning around 1% of the total of bins in Kardex ZKDX1001. This does not return much satisfaction in the space management problem of Kardex ZKDX1001. Besides that, the goal of this research would not be reached.

Research to obsolete parts in unnecessary bins found something else that is interesting. This is the total number of bins containing obsolete parts. Obsolete parts stay in the warehouse until someone looks at them, which can sometimes take years. In continuing of 10.5, an indication is provided about the number of obsolete bins, the current procedure for removing obsolete parts is presented and an option to improve this procedure is provided in the end.

10.5.1 Quantification of obsolete bins

Research to bins containing parts without demand and in the warehouse for longer than six months results in 1326 bins containing obsoletes. The signal codes for these 1326 bins have to be verified before obsolete bins can be released. To be able to say something reliable about the number of bins containing obsolete parts, signal codes have to be updated in deliberation with program managers. This was not performed within this duration of the project since the time and the necessity was not there.

Table 11: Total of excess and obsolete parts

Number of bins that could be reduced	*Should be code*	*Code*
Excess (EOL)	1240	368
Obsolete (OBS)	1326	82
Total	2566	450

The “Should be codes” in table 11 are determined as follows:

Total: The number of bins with parts without demand in the upcoming year
Obsolete: The number of bins with parts without demand and aging > 180 days
Excess: Total - Obsolete

Results

The total number of bins that could be released when all excess and obsolete parts would be removed from the Kardex,ZKDX1001 is 2566. Among them 1326 obsoletes.

The table shows that 1244 bins are not coded as obsolete, while the should be codes (column 2) assumes they are (1326 – 82 = 1244). According to the number of bins coded OBS and EOL, there are 450 of 9755 bins in the VLM systems that contain excess or obsolete parts. The assigned codes are possibly not accurate, since signal codes are updated at random moments, and approval from program managers and supply chain analyzers is needed to assign a code.

Employees are continuously working on decreasing the amount of obsolete and excess inventory. The problem here is that the actions to decrease the amount of obsolete and excess inventory are only one-sided. Decreasing attempts only focus on optimizing order quantities and order dates. Decreasing the number of obsolete and excess parts that is already stored in the warehouse is not tackled. When the company decides to do this, the number of released bins could rise to the extend shown in table 11.

What currently happens with obsolete inventory is described below.

10.5.2 What happens with obsolete parts in the warehouse

Benchmark knows that there are excessed and obsolete parts that do not necessarily have to stay in the warehouse. For a long time, nobody was looking to these parts, causing them to stay in the warehouse until somebody noticed them. Since four years, Benchmark is more actively trying to remove obsolete parts from the warehouse. One employee is working on this, together with the purchase manager and program managers. Once in every two weeks, the three sit together to look at parts that are obsolete and discuss about which parts could be removed.

Investigated obsolescence data

Data that is discussed during the meetings is based on obsolete inventory according to Sharepoint. Sharepoint displays excess and obsoletes inventory data, based on daily exports from Baan. The currently investigated data has its drawbacks. The most important one is that discussions only focus on the top 30 of obsolete parts in value. Meaning that only parts with highest value are investigated. The amount of space the parts occupy inside the warehouse is not taken into account at all.

Removing obsolete inventory

Obsolete inventory is removed from the warehouse occasionally. Only one employee is actively working on removing obsolete inventory, next to his real function at the company. He implies to not have enough time for actively removing obsolete inventory. When he has time, he makes a list of the top 10 or 30 of obsolete inventory. The necessity of the obsolete inventory is discussed with the program manager of the corresponding customer. The parts that end up to be approved for removing can leave the main warehouse to several places. These are the consigned warehouse, the customer the parts were purchased for, a distributor of abundant parts, or the trash.

Option 1: Consigned warehouse

Benchmark has a special warehouse in the main warehouse, called “consigned warehouse”. This warehouse is storing products for customers Thales and OTN. In this warehouse, products can be stored if they are no longer necessary. The difference between consigned and normal warehouse is that the customer is paying for the consigned warehouse. Parts laying here are property of the customer. The main purpose of this warehouse is to have parts in possession to be able to repair broken products. The disadvantage of this warehouse is that it is small and currently full. Selling or moving parts from normal to consigned or from consigned to outside is hard, because parts are old and not used in production anymore.

Option 2: Sold to customer

Obsolete inventory will after considering consigned, always first be offered to the customer. When the customer does not want the parts, parts can be offered to other companies.

Option 3: Sold to distributor

If the parts cannot be stored as consigned and if the customer does not want them, option 3 follows. To be able to sell a great diversity of parts, distributor sites are used to sell the parts. Currently, the parts are sold at two distributor sites: America2 and Texim. When parts are sold to these distributors, the parts are send there and wait at the distributor to be sold. Benchmark receives a massage when the parts have been sold. Selling the parts can take years, since obsolete mechanic parts are not very hot items.

Option 4: Trash

The last option is to throw the parts away. Obsolete parts that could not be sold or placed in the consigned warehouse, have to be thrown away to win space in the VLM. This process often takes a long time, since option 1 to 3 have to be considered first. The priority to walk through all these steps is low, so it usually takes a long time before obsolete parts finally end in the trash. This is caused by lack of time, money or manpower.

10.5.3 What can be done to improve the process of removing obsolete inventory in the VLM

Before obsolete inventory can be removed or excessed and/or obsolete inventory can be relocated, several steps have to be made.

Step 1: Updating signal codes

The first step is updating the signal codes of parts in the VLM. Based on the updated information, a more reliable indication of the number of obsolete parts can be used.

Step 2: Make space in consigned warehouse

The consigned warehouse is currently full, meaning that no more obsolete or excess parts can be removed from VLM systems to consigned warehouse. There are currently 1300 parts that are waiting to be removed from the consigned warehouse. When the company would apply this cleaning policy more active, storing locations are released for obsolete parts.

Step 3: Remove obsolete parts from Kardex ZKDX1001

Relocating parts from the VLM systems to the consigned warehouse releases bins. Other more active parts can now be stored in the VLM.